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Impact of Logistics on Readiness and Life Cycle Cost: A Life Cycle Management Approach

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June 2010

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Utilizing logistics modeling, cost analysis, a test platform, which is the Light Armored Vehicle equipped with a 25mm Gun System (LAV-25) currently employed by the United States Marine Corps (USMC), the authors will determine the effects of logistics on Ao and the TLCC utilizing specific critical factors, such as mean time between maintenance (MTBM), mean down time (MDT), and operational tempo. The authors' research will show which of the Ao's synthetic parameters are more sensitive to maintaining specific levels of Ao and readiness risk in conjunction with the cost, and the authors will suggest alternatives to achieve Ao and readiness risk thresholds under specific cost constraints.

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IMPACT OF LOGISTICS ON READINESS AND LIFE CYCLE COST: A LIFE CYCLE MANAGEMENT APPROACH

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Utilizing logistics modeling, cost analysis, a test platform, which is the Light Armored Vehicle equipped with a 25mm Gun System (LAV-25) currently employed by the United States Marine Corps (USMC), the authors will determine the effects of logistics on Ao and the TLCC utilizing specific critical factors, such as mean time between maintenance (MTBM), mean down time (MDT), and operational tempo. The authors' research will show which of the Ao's synthetic parameters are more sensitive to maintaining specific levels of Ao and readiness risk in conjunction with the cost, and the authors will suggest alternatives to achieve Ao and readiness risk thresholds under specific cost constraints.

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LIST OF ACRONYMS AND ABBREVIATIONS

Ai	Inherent Availability
Ao	Operational Availability
ARROWS	Aviation Retail Requirements Oriented to Weapon Replaceable Assemblies
DoD	Department of Defense
DoDD	DoD Directive
GAO	Government Accountability Office
IROAN	Inspect and Repair As Necessary
KPP	Key Performance Parameters
LAV	Light Armored Vehicle
LCC	Life Cycle Cost
MadmDT	Mean Administrative Delay Time
MC	Maintenance Center
MCDSS:	Marine Corps Decision Support System
MCLB	Marine Corps Logistic Base
MDAPs	Major Defense Acquisition Programs
MLDT	Mean Logistics Delay Time
MMT	Mean Maintenance Time
MOADT	Mean Outside Assistance Delay Time
MRAP	Mine Resistant Ambush Protected
MSRT	Mean Supply Response Time
MTBF	Mean Time between Failures
MTMB	Mean Time between Maintenance

MTTR	Mean Time to Repair
M&S	Modeling and Simulation
O&S	Operational and Support
Op-Tempo	Operational Tempo
PBA	Performance-Based Agreements
PBL	Performance-Based Logistics
PM	Program Manager
PPBE	Planning, Programming, Budgeting, and Execution
QDR	Quadrennial Defense Review
RBS	Readiness Based Sparing
RCM	Reliability Centered Maintenance
RFI	Ready-for-Issue
R-TOC	Reduction in Total Ownership Cost
R&D	Research and Development
SBCT	Stryker Brigade Combat Teams
SECREPS	Secondary Repairables
SOW	Statement of Work
TLCSM	Total Life Cycle Systems Management
TOC	Total Ownership Cost
UK MOD	United Kingdom Ministry of Defense
USD (AT&L)	Under Secretary of Defense (Acquisition, Technology, and Logistics)
USMC	United States Marine Corps

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– Major Andreas Balafas

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– Major Stavros Krimizas

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– Lieutenant John Stage

I. INTRODUCTION

A. BACKGROUND

The Department of Defense (DoD) continually works to shape policies to sustain excellence in combat effectiveness. The ability of warfighters to accomplish their mission relies on personnel and weapon systems/equipment readiness. The readiness measure is the operational availability (Ao). The personnel readiness depends on planning, contingency planning, planning execution, situational awareness, and timely decisions for the best primary or alternative planning. All the above depend on training and weapon systems/equipment readiness. Therefore, equipment readiness is the fundamental factor for mission success.

Readiness and its measure of operational availability have been integrated in the acquisition process, affecting decision making. In the early phase of an acquisition an initial Ao threshold is created to support the mission requirements. This initial Ao threshold is used in performance-based contracts in order to reduce the buyers' risk and the total life cycle cost (LCC). The probability a contractor will fail to deliver a desired threshold of Ao is measured with another metric, which is "readiness risk," and it is associated with contract performance.

B. PURPOSE

The ability of the United States Marine Corps (USMC) to fight and meet the demands of the National Military Strategy depends on the operational availability and readiness risk (probability of achieving a threshold Ao) of its weapon systems. Moreover, Ao has been integrated in the acquisition process (Department of the Navy, 2003), which greatly affects decision making. In the early phases of an acquisition, an initial Ao threshold is created to support mission requirements. The initial Ao threshold is used in performance-based contracts in order to reduce the buyers' risk and the total life cycle cost. The

intentions of the DoD and commercial defense industries are to improve the Ao of weapon systems at reduced costs. In addition, operational commanders are concerned with maintaining an optimal Ao for their weapons systems. Moreover, they are concerned with balancing this Ao with readiness risk and cost.

Ao depends on a system component's reliability (failure rates), maintainability (e.g., repair time) of failed components, and supportability (e.g., transportation, administration, logistics delays). Maintainability depends on the number of components' spares in the spare pool and maintenance capacity (turnaround time). Another factor that influences the Ao is operational tempo (Op-Tempo), which is how long (the total work time) a unit deploys or goes to the field.

Utilizing logistics modeling and cost analysis techniques, this MBA report seeks to determine the effects of logistics on Ao and TLCC of the Light Armored Vehicle equipped with a 25mm Gun System (LAV-25) currently employed by the USMC. The authors' research and modeling will include 76 LAV-25s normally deployed with a Marine Expeditionary Force (MEF) for a life cycle of 20 years. For the test platform, the USMC uses 1,570 different parts in order to accomplish maintenance on a single LAV-25. The purchase of all of these parts contributed $29,372,715 to the TLCC of the LAV-25 for the years 2007-2009. Utilizing specific critical factors, such as mean time between maintenance (MTBM), mean down time (MDT), and Op-Tempo, the authors' research via the use of a simulation model will show which of the Ao's synthetic parameters are more sensitive in terms of maintaining specific levels of Ao and readiness risk in conjunction with cost. In addition, the research will suggest alternatives with optimal allocation of the critical factor to achieve Ao and readiness risk thresholds under specific cost constraints.

C. RESEARCH QUESTION

The authors' project, using a model developed with Arena simulation software and an Excel spreadsheet, will develop a methodology to investigate alternatives for Ao, LCC, and readiness risk. In this project the authors will research the following questions:

- Which logistics factors have the biggest impact on Ao, readiness risk, and the total life cycle cost?
- Which combination of logistics factors is appropriate in order to find the optimum overall solution (meeting the minimum satisfactory levels of Ao, readiness risk, and total life cycle cost)?
- What is the impact of logistics on acquisition and performance-based logistics? How can modeling and simulation tools be used in the acquisition process?

D. SCOPE AND METHODOLOGY

1. Scope

This report, in terms of dollars and risk (readiness risk), will demonstrate which of the Ao's component factors in a weapon system are worthy to change, thus, improving the system's Ao during the life cycle management. It examines two realistic options. The first option (part one) will examine and suggest alternative solutions after the procurement, and during the operation and support (O&S) phase, into the maintainability (i.e., turnaround times during the maintenance) and supportability (i.e., logistics delay times during the administration, or the transportation, or changing the spares' inventory), assuming that the components' failures rate are given (the warfighters and the logistic teams cannot change these factors), as well as the Op-Tempo. The second option (part two) will examine and suggest alternative solutions before or during the system acquisition, and during the research and development (R&D) and investment phases, into the components reliability (i.e., during the procurement the acquisition team could negotiate a minimum threshold for the components failure rate in order to obtain a minimum Ao for a weapon's life cycle).

2. Methodology

This report adopts and uses an Arena simulation model and an Excel spreadsheet model (Kang, McDonald, Thompson, Phillips, Low, & Kim, 2009) that can estimate distributions of the average Ao, readiness risk, and average LCC for 257 scenarios for each case. For each case, predetermined mean factor values will be used in accordance with the initial data and the report's assumptions. They will be generated random values (stochastic element that occurs during the generation of the pseudo-random numbers) in accordance with the factor ranges and mean values. With the 257 scenarios for each case, the variable factors' values are trying to simulate the dynamic situation of a major weapon system during its life operation, in peace time or under contingency operations.

The initial case begins with a baseline, which became the standard throughout the research project. Correlating the input data with the results the authors will find which of the input factors have the greater impact on Ao, readiness risk, and LCC. Then the authors will try alternatives (i.e., changing the range value of the factors that had the greater impact) and analyze the results. In accordance with the sensitivity analysis and the results they will suggest alternative maintenance policies that will have impact on desired maintainability, supportability, and finally on Ao and readiness risk. Furthermore, the authors will examine if an initial Ao threshold in the early phase of an acquisition process could be acceptable or what is the risk in accordance with the components' reliability and maintainability that a contractor has offered.

E. ORGANIZATION OF STUDY

This report is organized into six chapters. Chapter II includes background and literature reviews for Ao metrics, performance-based logistics (PBL), and LCC. Chapter III discusses the Arena simulation model, the LCC Excel spreadsheet model, and the potential for warfighters, logistic teams, program managers (PMs), and contracting officers to use them as a decision support tool

in making better judgments. Chapter IV examines the impact of logistic on acquisition management. Chapter V presents the initial case, examines the weight impact of the input factors on Ao, readiness risk and LCC, and analyzes alternatives for improvement. Chapter VI offers the authors' overall conclusions and recommendations.

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II. BACKGROUND

A. USMC MAINTENANCE PROGRAM

1. Introduction

Maintenance in the Marine Corps is broadly defined as those actions required to restore materiel to an operating condition or to maintain materiel in a serviceable condition. To accomplish the task of maintaining ground equipment such as the LAV-25, the Marine Corps maintenance system is broken down into three categories: organizational, intermediate, and depot. To allow for better organization and to adequately identify the capabilities of each unit (e.g., personnel, tools, equipment, and parts) within the maintenance system, organizational and intermediate levels of maintenance are further subdivided into two echelons of maintenance (EOM) with depot level maintenance containing one EOM (Department of the Navy, 1989).

2. Description of Maintenance Categories

a. Organizational Maintenance

Organizational maintenance is the preventive (scheduled) or unscheduled maintenance that is required and conducted by the unit, which has the equipment assigned as part of its Table of Equipment (TOE) (Department of the Navy, 1989).

b. Intermediate Maintenance

Intermediate maintenance is the maintenance conducted by activities designated to provide direct support to end users (warfighters). This category of maintenance includes such activities as the repair and replacement of damaged or unserviceable parts, as well as calibration. In addition, personnel assigned to the intermediate maintenance activity provide technical assistance to end users as necessary. Third and 4th echelons of maintenance are normally

conducted at this level, with the 2nd echelon being completed when the workload at the organizational level exceeds its capacity (Department of the Navy, 1989).

c. Depot Maintenance

Depot maintenance is the maintenance that requires parts, subassemblies, assemblies, or entire end items to be overhauled or completely rebuilt. This category also includes the modification of existing parts, subassemblies, assemblies, and end items, and the performance testing of these modifications. Depot level maintenance supports lower level maintenance categories by conducting maintenance that is beyond its capabilities and responsibilities and by providing technical assistance when required. The 5th echelon maintenance is conducted at the depot level (Department of the Navy, 1989).

3. Description of Echelons of Maintenance

a. 1st Echelon

The 1st echelon conducts either scheduled (preventive) or unscheduled maintenance, performed by the equipment owner or operator, which a unit has assigned as part of its Table of Equipment (TOE). This EOM includes such tasks as lubrication, preservation, cleaning, and necessary minor adjustments to allow the equipment to function properly. Minor repairs, parts replacement, and post-repair adjustments and operational testing are also conducted at this level in accordance with pertinent technical publications (Department of the Navy, 1989).

b. 2nd Echelon

The 2nd echelon is maintenance that is beyond the capabilities of the first EOM and requires the organization to have specially trained personnel assigned and advanced facilities and equipment to complete. All additional repair parts, test equipment, tools, supplies, and specially trained personnel required by activities responsible for conducting this EOM are specifically

allocated by orders and publications. Maintenance performed at this level includes scheduled maintenance, easily diagnosed and traced malfunctions, and the replacement of major components that can be easily removed and reinstalled and do not require significant adjustments or testing (Department of the Navy, 1989).

c. 3rd Echelon

The 3rd echelon maintenance is conducted by specially trained personnel and is permissible at the intermediate or organizational levels only as authorized by appropriate publications. This EOM includes the diagnosis of malfunctions at the equipment and module level; the use of test, measurement, and diagnostic equipment (TMDE) for troubleshooting, adjustment, and alignment of modules; repair by replacement of components not requiring extensive post-maintenance testing; and modular component cleaning, seal replacement and the installation of external parts. This level of maintenance also includes the completion of minor bodywork and emissions testing of internal combustion engines (Department of the Navy, 1989).

d. 4th Echelon

The 4th echelon maintenance is conducted within intermediate maintenance activities. This EOM is normally performed at semi-fixed or permanent repair facilities and includes such tasks as diagnostics, troubleshooting, calibration, and the repair of malfunctions of printed circuit boards and integrated solid-state devices and circuits down to the component level. In addition, the repair of items such as valves, tappets, and seats by means of grinding, adjusting, or replacement is also performed at this EOM. This level of maintenance also includes heavy body, hull turret, and frame repair (Department of the Navy, 1989).

e. 5th Echelon

The 5th echelon maintenance is completed at the depot level and at intermediate maintenance activities when specially permitted by the Commandant of the Marine Corps (CMC) code. Maintenance at this echelon includes the complete overhaul or rebuilding of parts, subassemblies, assemblies, or entire end items. This category also includes modifications to existing parts, subassemblies, assemblies, and end items, and the performance testing of these modifications. Depot level maintenance supports lower level maintenance categories by conducting maintenance that is beyond its capabilities and responsibilities and by providing technical assistance when required (Department of the Navy, 1989).

B. OPERATIONAL AVAILABILITY (A_O)

Operational availability (Ao) is the primary performance measure of readiness for weapon systems, subsystems, and equipment (Department of the Navy, 2003). Before defining Ao, it is necessary to define readiness and reliability.

According to the *Glossary of Defense Acquisition Acronyms and Terms* (2005), readiness is the

> state of preparedness of forces or weapon system or systems to meet a mission or to warfight. Based on adequate and trained personnel, material condition, supplies/reserves of support system and ammunition, numbers of units available, etc. (p. B-137)

According to the *OPNAV INSTRUCTION 3000.12A Operational Availability Handbook* (2003) the definition of reliability is

> the ability of a system and its part to perform its intended mission for a specified period of time under state conditions without failure, degradation or demand on the support system. (p. 67)

The definition of Ao for the U.S. Navy is given in the *OPNAV INSTRUCTION 3000.12A Operational Availability Handbook* (2003) as follows:

> Operational Availability (Ao) is defined as the probability that the system will be ready to perform its specified function, in its specified and intended operational environment, when called for at a random point in time. (p. 10)

In the same handbook Ao is given as follows:

> Operational Availability is a probability function of reliability, maintainability and supportability components. Very simply, this equation is:
>
> $$Ao = \frac{Up\,Time}{Total\,Time} = \frac{Up\,Time}{Up\,Time + Down\,Time}$$
>
> Total time has two sub-factors, "up time" and "down time". The "up time" is the time a system is operational between failures. The "down time" is the time the system is not operational. Operational Availability is the supportability calculation of the equipment/system (hardware & software) in terms of predicted Reliability called Mean Time between Failures (MTBF) and predicted Maintainability in terms of Mean Time to Repair (MTTR) and designed supportability, called Mean Logistics Delay Time (MLDT). (Department of the Navy, 2003, p. 4)

Therefore, the above equation can be written as follows:

$$Ao = \frac{MTBF}{MTBF + MTTR + MLDT}$$

The final analytical form of the equation will be presented at the end of Section B when MTBF, MTTR, and MLDT have been discussed.

As already stated, the terms mean time between failures (MTBF), mean time to repair (MTTR), and mean logistics delay times (MLDT) are discussed later. The term mean logistics delay times (MLDT) defines the support activities, such as re-order, transportation, repair time, etc. If this term is omitted then the above equation defines the inherent availability (Ai), which measures the inherent availability performance of the system (Department of the Navy, 2003). Obviously Ai is referring to an ideal support environment where there are no

constraints regarding logistics (i.e., infinite spare parts, no re-order or transportation delays, etc). However, Ai can be used in the design phase of a system or when it is desired to measure the effects of MTBF and MTTR on the availability of a system.

1. Mean Time Between Failures (MTBF)

According to the *OPNAV INSTRUCTION 3000.12A Operational Availability Handbook* (2003) the mean time between failures is

> for a particular interval, the total functional life of a population of an item divided by the total number of failures within the population. The definition holds for time, rounds, miles, events, or other measures of life unit. (Department of the Navy, 2003, p. 63)

Practically it is the system's operational time between failures. MTBF is the reciprocal of the failure rate, i.e.,

$$MTBF = \frac{1}{\lambda}$$, where λ is the failure rate.

Various software programs and simulation models have been developed to predict the MTBF of a weapon system. Usually, the users determine and select components/parts that are critical and when those components fail the whole system is "down." The MTBF of these components/parts are used in order to determine the MTBF of the whole system.

2. Mean Time to Repair (MTTR)

One of the two "downtime" measures is the mean time to repair (MTTR); the other is the mean logistics delay time (MLDT). The MTTR is the measure for the maintainability too. According to the *OPNAV INSTRUCTION 3000.12A Operational Availability Handbook* (2003), the mean time to repair is

> the average time for a successful repair and includes the average time to remove interference, remote, replace and test the fail

> component, return the equipment to its original condition, and replace and retest any system (interference) removed to get to the failed equipment. (p. 6)

It depends on the level of the components' spares in the spare pool (in case of replacing the failure components) or the three levels[1] of maintenance capacity (in case of repairing it). On the other hand, the spares availability and the maintenance capacity depend on the available budgets, which are categorized as the operational and maintenance (O&M) budgets. Several models for spares are currently being used and are known as Readiness Based Sparing[2] (RBS) models in the U.S. Navy. Correspondingly, the Aviation Retail Requirements Oriented to Weapon Replaceable Assemblies (ARROWS) model is used by aviation.

3. Mean Logistics Delay Time (MLDT)

The mean logistics delay time (MLDT) is a measure for the support activities, such as re-ordering, transportation, repair time, etc (Department of the Navy, 2003). The MLDT depends on the mean supply response time (MSRT), mean outside assistance delay time (MOADT), and mean administrative delay Time (MadmDT). The MSRT is "the average portion of down time awaiting receipt of the spare component" (Department of the Navy, 2003, p. 63). It is the single greatest driver in MLDT (Department of the Navy, 2003). The MOADT is the "average time awaiting maintenance teams from other locations or depot" (Department of the Navy, 2003, p.63) The MadmDT is the average time awaiting logistics resources (administrative resources) other than spare parts (e.g., awaiting qualified maintenance personnel, support equipment, technical data, training, facilities etc) (Department of the Navy, 2003, p. 4).

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[1] The three level of maintenance are organizational (O), intermediate (I), and depot (D) (Department of the Navy, 2003).

[2] Readiness Based Sparing (RBS) is the practice of using advanced analytics to set spare levels and locations to maximize system readiness. RBS has been part of department practice since the 1960s when it was used to optimize aircraft availability, and is incorporated into the DoD Supply Chain Materiel Management Regulation (DoD 4140.1-R) as the preferred method for calculating inventory levels. The services and DLA have agreed to work together to implement commercial off the shelf (COTS)-based RBS models (Supply Chain Integration, 2009).

Hence, the Ao is determined by the system's component level reliability (the reciprocal of failure rates-MTBF), maintainability (repair time-MTTR) of the failure components or the entire system, and the supportability (logistic delay time-MLDT). Therefore, the Ao mathematical definition is analyzed as follows:

$$Ao = \frac{MTBF}{MTBF + MDT\ (Mean\ Down\ Time)} = \frac{MTBF}{MTBF + MTTR + MLDT}$$

$$\text{or}\ \ Ao = \frac{MTBF}{MTBF + MTTR + (MSRT + MOADT + MadmDT)}$$

This will be the mathematical definition that will be used for the purpose of this project (Figure 1).

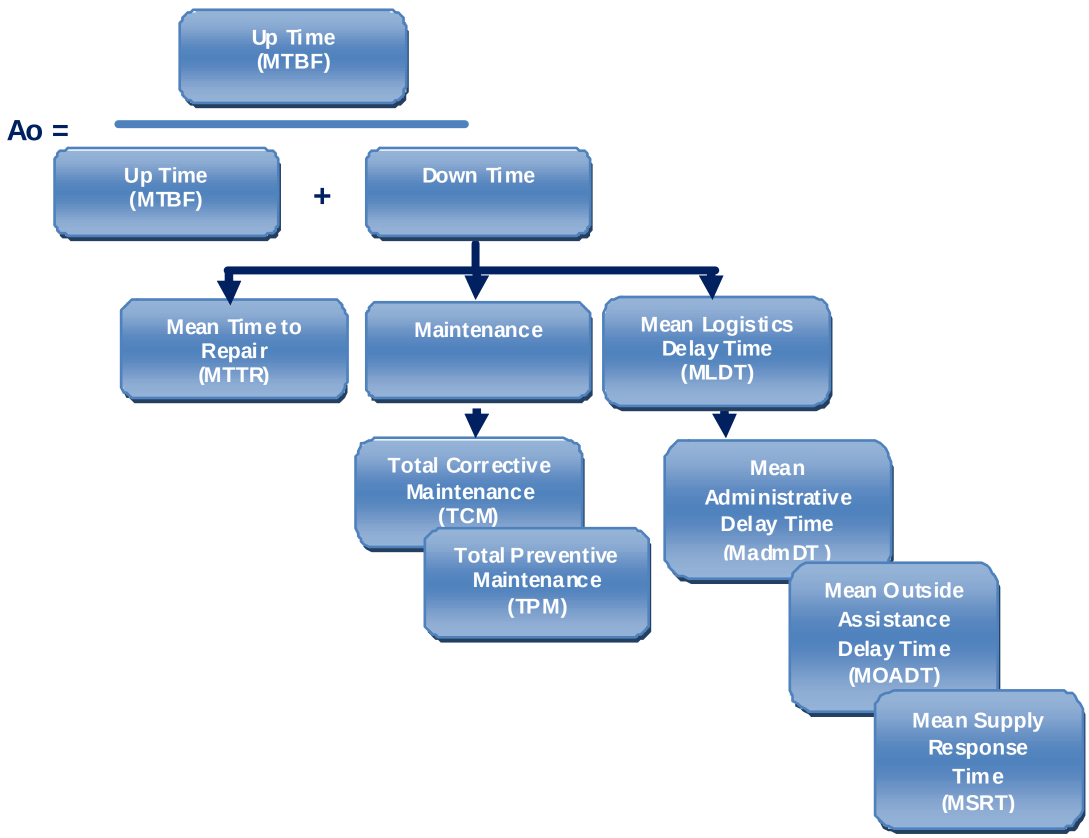


Figure 1. Operational Availability (Ao) Components

4. Operation Availability in Acquisition and Readiness Risk

Operational availability is a crucial performance measure as it depicts the weapon systems that can participate in operations. Also, the readiness and its measure Ao have been integrated in the acquisition process. The Ao is a key performance parameter (KPP)[3] for deciding the acquisition of a weapon system and it affects the total life cycle cost. In the early phase of an acquisition an initial Ao threshold is created to support the mission requirements. This initial Ao threshold is used in "performance-based contracts" to reduce the buyers' risk and total life cycle cost. The operational availability metric helps the program manager to upgrade a system's capabilities, and at the same time sustain and/or increase readiness and cost performance (Department of the Navy, 2003).

In the last decade there has been a preference for buying performance instead of a product or service using performance-based logistics[4] (PBL) contracts and performance-based agreements[5] (PBA). Ao is identified as the one of two valued performance outcomes; the other one is readiness risk (Kang, Doerr, & Sanchez, 2006). PBL are the DoD's preferred–-required for new–-sustainment strategy (Department of Defense, 2008). The "readiness risk" is a metric that measures the probability that a contractor (e.g., vendor, depot, maintenance unit) will fail to deliver a desired threshold of Ao in a contract, and it

[3] Key performance parameters (KPPs): Those attributes or characteristics of a system that are considered critical or essential to the development of an effective military capability and those attributes that make a significant contribution to the key characteristics as defined in the Joint Operations Concept. KPPs are validated by the Joint Requirements Oversight Council (JROC) for JROC Interest documents, and by the DoD Component for Joint Integration or Independent documents. The Capability Development Document (CDD) and the Capability Production Document (CPD) KPPs are included verbatim in the Acquisition Program Baseline (APB) (*Defense Acquisition Acronyms and Terms*, 2005).

[4] Performance-based logistics (PBL): The preferred sustainment strategy for weapon system product support that employs the purchase of support as an integrated, affordable performance package designed to optimize system readiness. PBL meets performance goals for a weapon system through a support structure based on long-term performance agreements with clear lines of authority and responsibility (*Defense Acquisition Acronyms and Terms*, 2005).

[5] Performance-based agreements (PBAs): establish a negotiated baseline of performance, and corresponding support necessary to achieve that performance, whether provided by commercial or organic support providers. PBAs with users specify the level of operational support and performance required by users (AT&L Integrated Framework Chart).

is associated with the contract performance. For this, it is essential to develop simulation models for testing and evaluating Ao and the impact it has on total life cycle management. Many works identify this need, among them Gary A. Pryor from the U.S. Army Training and Doctrine command, who includes it in the conclusion of his article regarding the methodology for estimating Ao for military systems (Pryor, 2008).

C. LIFE CYCLE COST (LCC)

Life cycle cost (LCC) is the total government or ownership cost of all categories of cost during the whole weapon system's life (Department of the Navy, 2003). The total LCC includes the research and development (R&D) cost, investment cost (production cost), operating and support (O&S) cost, and disposal cost (Figure 2).

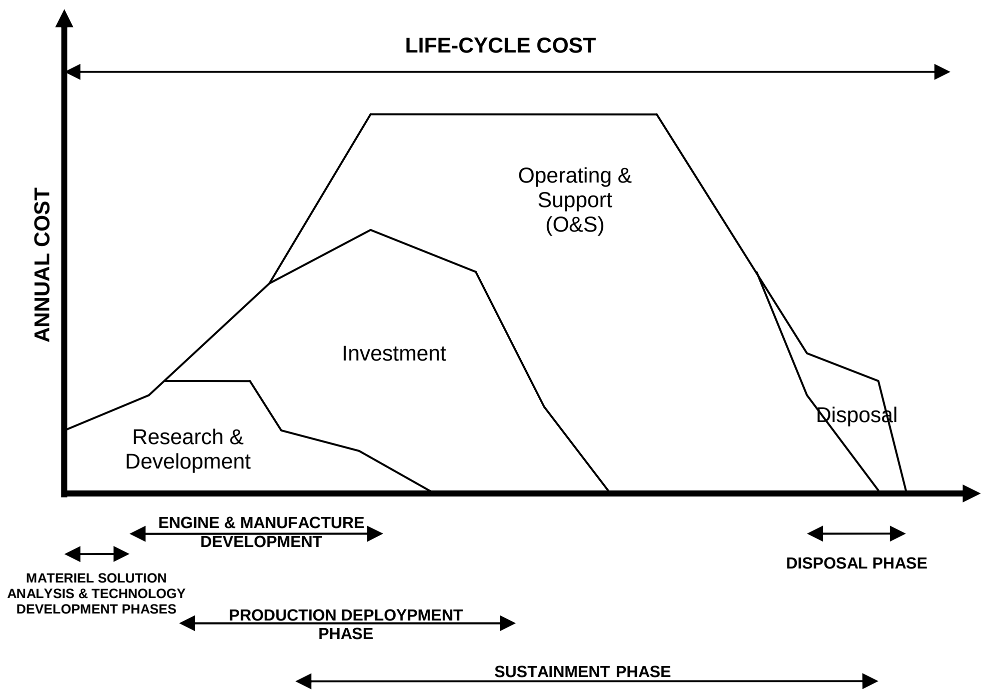


Figure 2. Life Cycle Cost Category Definitions (From: *Defense Acquisition Guidebook*, 2010)

The Department of Defense refers to total LCC as the total ownership cost (TOC). The TOC is

> designed to determine the true cost of design, development, ownership and support of DoD weapons systems. At the DoD level, Total Ownership Cost is comprised of the costs to research, develop, acquire, own, operate and dispose of weapon systems, other equipment and real property, the costs to recruit, retain, separate, and otherwise support military and civilian personnel, and all other costs of the business operations of the DoD. At the individual program level, Total Ownership Cost is synonymous with the life cycle cost of the system. (Department of the Navy, 2003, p. 69)

For the purposes of this project the authors consider that total LCC is identical to TOC. The assumption of this project, discussed in Chapter III, is that the total LCC is the O&S cost.

The O&S cost consists of the biggest portion of the LCC (60-80%), and depends on a system's reliability, maintainability, and supportability (Naegle, 2008). The limited funds and resources (number of systems, infrastructures, and personnel) are a major constraint for the Ao and they set a ceiling for the pre-planning of LCC. As the Ao is a critical factor for operational effectiveness, many models are trying to find the optimum combination of maintainability and supportability in order to improve Ao and minimize LCC. Those models are taking into account the budget constraints.

The intention of the Department of Defense and the commercial defense industry is to improve weapons system Ao at a reduced cost and especially the O&S cost. This means reliability, maintainability, and supportability improvement at a reduced cost. The possible alternative actions for Ao improvement with reduced cost are as follows:

1. Reduction of the occurrence of system failure (better reliability).
2. Faster equipment maintenance (improve maintainability).
3. Less logistic delays (better supportability).
4. A combination of all or some of the above.

There are LCC models that calculate the cost of each alternative, and they are utilized as decision tools for the buyers (government or owners), warfighters, system makers, and contractors (vendors). Furthermore, the LCC is used in the acquisition process; the initial estimation of the program's cost serves as a guide during the life cycle of the system. There are models that continuously collect and monitor operations and logistics data about reliability, maintainability, and supportability (e.g., the number of systems, the past Ao, the failure rate, the times for individual work, deliveries, services, the individual subsystem's cost, the number of depots or service-maintenance units, spares, personnel, salaries, etc). The models estimate the system's real cost calculation and the deviation between the pre-scheduled and the real cost.

During the system's program initiation, one has to predict the future reliability, maintainability, and supportability prices to estimate the TOC. The prediction involves the risk for an accurate prediction (which is the probability the calculated values and initial LCC will fail to predict the future real values). Utilizing a simple model such as an Excel spreadsheet, one can change parameters or combine them, and thus be able to conduct sensitivity analyses and see how all the previous factors influence the total LCC. Even though the Excel spreadsheet model is a useful model, it still remains a static model without taking into account the dynamic interference between the Ao's synthetic parameters. This dynamic can be investigated by developing a simulation model with a software tool such as Arena. Using a combination of these models (Excel spreadsheet and Arena software), one can choose the best cost effectiveness solution or estimate the LCC for an alternative (e.g., an improvement in Ao).

III. METHODOLOGY

A. BASELINE

In order to answer the question of which of the factors (components' rate failure (λ), number of spares in spare inventory, maintenance turnaround time (TAT), Op-Tempo) has the greater impact on the operational availability (Ao), and the life cycle cost (LCC), 257 different scenarios were drafted for each case. For each case, predetermined factor ranges or mean values will be used in accordance with the initial data and project's assumptions. Then, for each case they will be generated random values (stochastic element that occurs during the generation of the pseudo-random numbers) in accordance with the factor ranges and mean values. For generating the λ values the authors will take the following steps:

- Generate random values using a Poisson distribution with means in accordance with the fourth column of Table 6 (mean operating time between failures).
- Calculate the reciprocals of the Poisson random variates generated in the previous step; the result will be the λ values (which are not integers) that will be used for this project.

For the rest of the factors the authors will use a normal distribution; the mean μ and the standard deviation σ are described in the input data table for each case.

With the 257 scenarios for each case, the variable factors' values are trying to simulate the dynamic situation of a major weapon system during its life operation in peace time or under contingency operations. To measure changes in Ao and LCC, a simulation model, which is a combination of Arena and Excel spreadsheet software simulations, will be used for comparing several options. The Arena software simulation program can be used to support results that incorporate the interactions between the factors, when one or more parameters change in each scenario. By using the components' MTBF, number of available spares in the inventory, maintenance TAT (in this project the maintenance TAT

includes the MTTR and the MLDT) and Op-Tempo as input parameters for each scenario in the Arena model, the authors can extract as output the average Ao for the system's life cycle. Then, using the Excel spreadsheet, they can calculate the LCC for each scenario.

Using the Ao values' distribution, the authors can extract the quantiles of Ao[6], and the readiness risk (the probability that an Ao value falls below a desired Ao threshold). That data and the cumulative Ao can be transferred in an Excel spreadsheet and be visualized in a chart for decision making. Returning back to the Excel spreadsheet, one can calculate the Ao, readiness risk, and LCC for each of the alternative cases.

B. ASSUMPTIONS

Due to the plethora of LAV-25 components, over 1,500, research on all cross-possible scenarios in conjunction with the input factors will be impractical and timeless. A good solution for the authors is to limit their research and modeling to a limited number of parts (using the Pareto principle, also known as the "80-20 rule")[7], especially those that are the most costly to buy or repair and are considered critical (if a failure occurs, the LAV is non-operational). The authors' research and simulation modeling will concentrate on five major critical repairable parts (Table 1). These five parts represent 65 percent[8] of the total cost of replacement parts currently maintained by the USMC for the LAV-25, and are considered critical (Table 1, criticality code "5").

[6] Quantiles are points taken at regular intervals from the cumulative distribution function (CDF) of a random variable. In the authors' case the Ao quantiles will be 5%, 10%, 15%, ... ,100% of Ao (Keller, 2009).

[7] The Pareto principle, also known as the "80-20 rule" and the law of the vital few and the principle of factor sparsity, states that, for many events, roughly 80% of the effects come from 20% of the causes.

[8] MCDSS: Marine Corps Decision Support System. Automated decision support system (logistics information systems) designed to support Logistic Command (LogCom) logistics managers, from the IM to the commander in strategic logistics decision-making processes. It provides data extracts from maintenance, inventory, and finance systems to perform decision support of the master work schedule planning and Depot Level Maintenance Program (DLMP) activities.

Part No	Part Name	Unit Price	Failure Rate[9]	SL Qty	Critical Code	SMR Code	Cum. Ext. Price	Cumulative % contribution to total cost
1	Sensor Unit, Laser	$89,794	0.000211638	2	5	PAFHD	$10,775,318	37%
2	Control Display Unit	$27,683	0.000363312	1	5	PAOFD	$13,848,172	47%
3	Differential, Driving	$22,475	0.0000890643	4	5	PAOHH	$16,118,151	55%
4	Engine, Diesel	$41,757	0.000109346	1	5	PAFHD	$17,663,146	60%
5	Engine, Diesel	$26,890	0.000126983	1	5	PAFHD	$18,738,755	64%

Table 1. LAV-25 Part Usage (After: *MCDSS 4.3.1.1, PartUsage_EO947, 2007-2009*) [8]

For the purpose of this project, the echelon turnaround times (TATs) are considered the sum of the repair time (MTTR), administration time, and transportation delay time. This project does not consider "cannibalization," the swapping of a working component from one downed LAV-25 to another.

The Excel spreadsheet model computes the operational and support (O&S) cost, a portion of the total life cycle cost, including spare, repair, transportation, and operation costs. For the purpose of this project the authors will consider the life cycle cost of the O&S cost.

Readiness risk is defined as the probability that Ao falls below a certain threshold level. For this report the authors set the threshold of Ao as 75% and the probability of not achieving this threshold (readiness risk) is Prob [Ao < 0.75] < 0.10 (i.e., readiness risk less than 10%). The target mean Ao is set to 85%.

[9] According to the data from Table 1, the failure rates were given as the number of failures per million days, which is too low. Even using one calendar day as a time unit, the failure rates still remain too low, or the components are unusually too reliable . Instead of the failures per million days in the authors' project they will use the provided data as failures per calendar hour. This assumption does not change the proportions between components' failures from the initial data.

C. MODELS

A combination of Arena and Excel spreadsheet software simulations were used in this project. These two models have been presented and developed by Kang et al. (2009). Even though the Excel spreadsheet model by itself is a simple and useful model for the decision makers (e.g., program manager, logistics designers, or financial administrators), it is a "static" model that does not take into account the dynamic interference (vicious cycle) between the Ao's synthetic parameters. For example, a decrease in MTBF decreases Ao and increases LCC, because low Ao increases the frequency of repairs and induces higher maintenance costs. Ao is further reduced when these increased maintenance costs eventually lead to budget reductions and force a reduction in the frequency of preventive maintenance. This "vicious cycle" (Figure 1) continuously lowers Ao, ultimately leading to high-cost corrective (unscheduled) maintenance, which further reduces Ao.

Arena can support results that incorporate the abovementioned vicious cycle (interactions) between factors, when one or more parameters are changed in each scenario. Using Arena input parameters such as MTBF, MTBM, MDLT, (in this project MTBM and MDLT are incorporated in the maintenance TAT) and the number of available spares, the authors can take as output the average Ao and its resulting readiness risk.

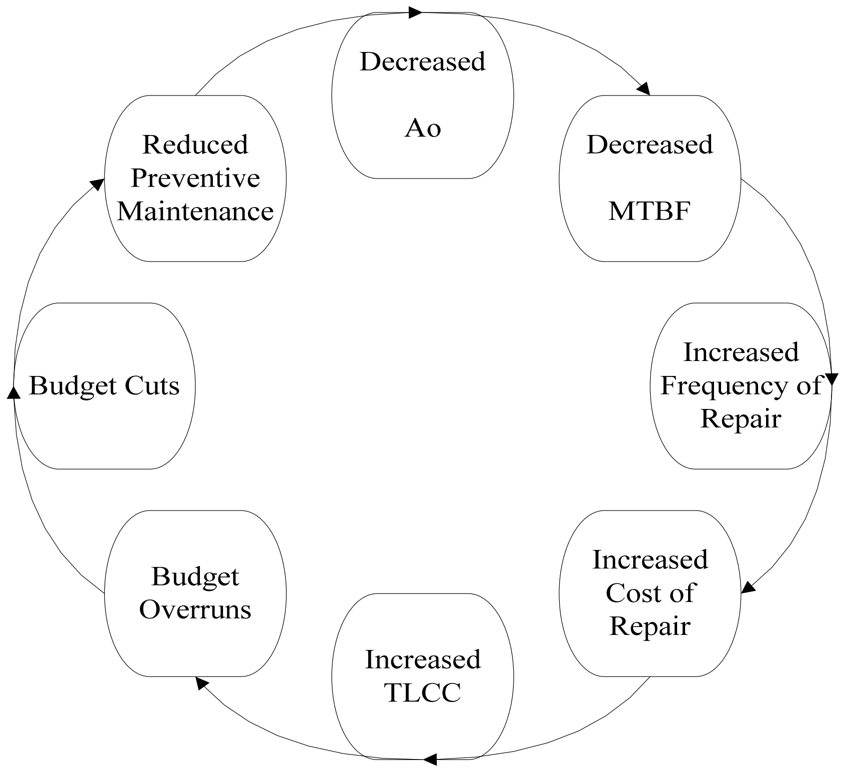


Figure 3. Vicious Cycle

1. Arena Simulation Model

The model was initially used for the Light Armored Vehicles 25 with a 25 mm Gun System (LAV-25) case study from Kang et al. (2009). When a critical component of the weapon system fails, the faulty component is removed from the system and a ready-for-issue (RFI) spare is installed. The faulty component is sent to the repair echelon. After the repair is complete, the component becomes an RFI spare and is sent to the spare inventory pool. If an RFI spare is not available at the repair echelon, the system will be grounded (and will become not mission capable) until an RFI spare is available (Figure 4). The failure of a noncritical component may degrade readiness, but the system is assumed to be operable (partially mission capable).

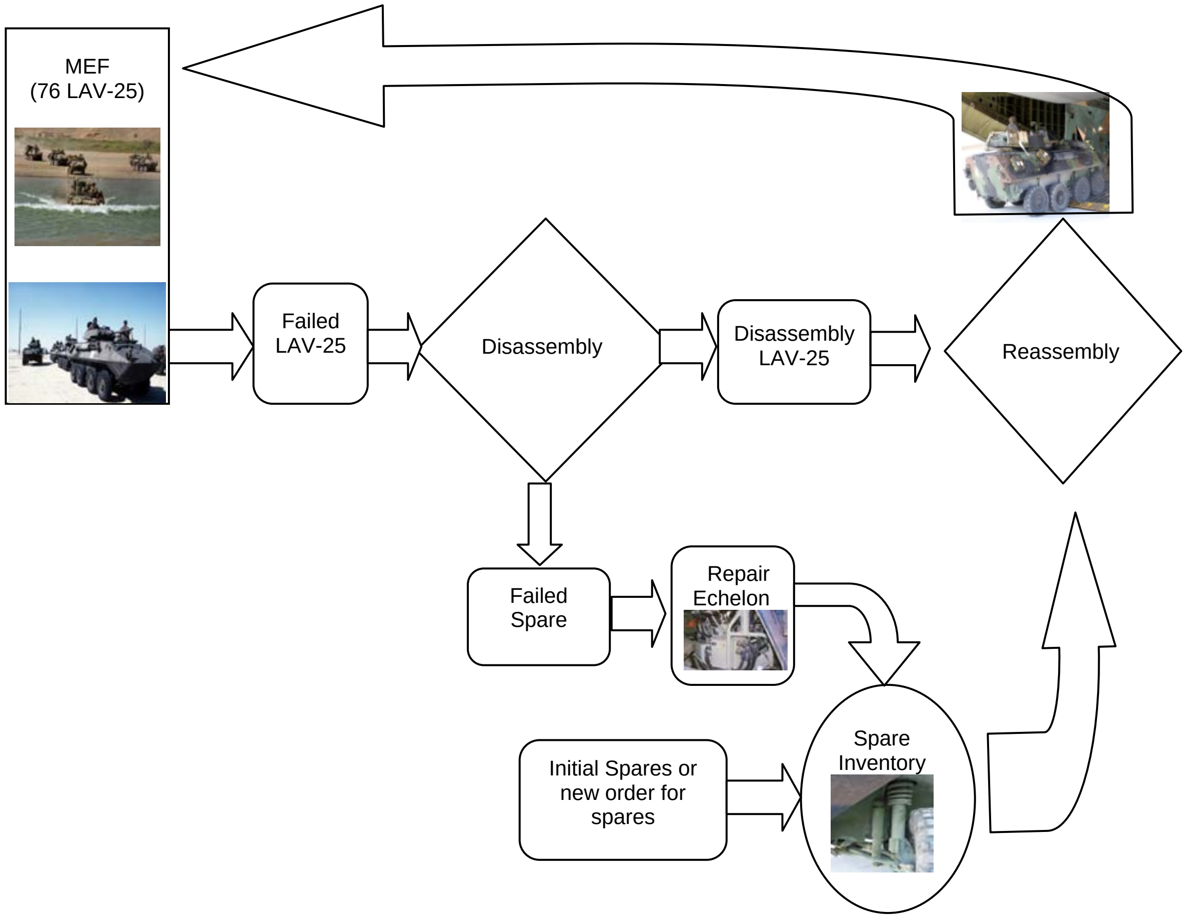


Figure 4. The Repair Cycle

A brief description of the Arena simulation model (it is used as a case study for the LAV-25) logic is as follows:

1. Input data are read from an Excel input spreadsheet that includes the input data for the corresponding scenario for each case. For each case the authors use 257 different scenarios.
2. For the model, 76 LAV-25s (as entities) are generated, which have been deployed as Marine Expeditionary Force (MEF).
3. In accordance with the input data, the model generates for each scenario five parts' failures times. The model looks for the smallest value between the five failures and whichever is the smallest value is the next failure time of the LAV-25s.

4. The "down" (non-operative) LAV-25 is transferred to the repair echelon and the faulty part is removed from the LAV-25. The number of fully mission capable (FMC) LAVs is reduced by one: $FMC = FMC - 1$.

5. The faulty part is sent to the repair echelon.

6. At the repair echelon the "down" LAV-25 becomes "up" (operative) if a spare part is available and accordance with the repair time. If a spare is installed and the LAV-25 returns back to the MEF, the number of FMC is now increased by one: FMC = FMC +1. Otherwise, the LAV-25 waits in the queue until a spare from the spare inventory is available.

7. After the delay into repair echelons as specified in the Excel input spreadsheet, the repaired part joins the spare inventory.

8. Steps 1-7 are repeated until the end of the simulation time.

9. At the end each of scenario, the simulation automatically calculates the average operational availability (Ao) as follows:

$$Ao = \frac{average\ FMC\ LAV}{total\ number\ of\ LAV}$$

Ao is a time-persistent variable and the average value of Ao must be "time-averaged" (Kelton, Sadowski, & Sturrock, 2007). The Arena model automatically computes the value. A sample screen shot of the LAV-25 Arena simulation model is given in Figure 5.

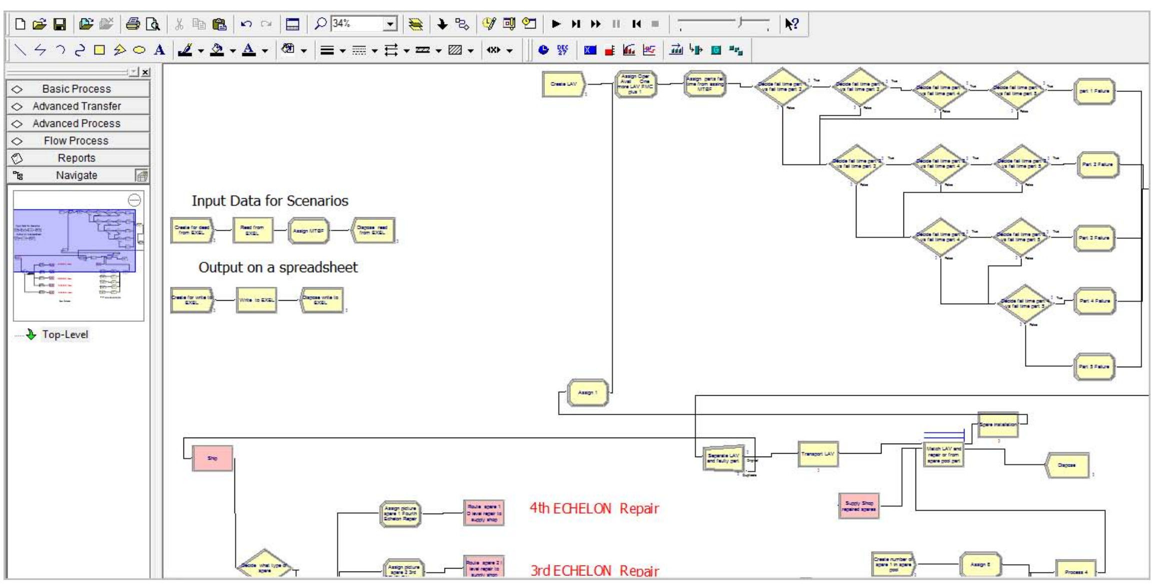


Figure 5. LAV-25 Arena Simulation Model (After: Kang et al., 2009)

For each scenario, the simulation model will use the following inputs (Figure 6, Columns A through M): the failure rates/hour for each of the five components (λ_i, i=1, 2…5): the number of spares stocked; the repair turnaround time (TAT) for each component (TAT includes the maintenance time, transportation, administration and logistic delays); and Op-Tempo (the annual work time in hours for the weapon system). For the failure rates, repair turnaround time for each component, and Op-Tempo, the input values will be random numbers (stochastic prices) generated based on an average value in accordance with the real data and the pre-defined value ranges from the authors' assumptions, or the alternatives. In the Arena simulation model, the authors will run a total of 257 scenarios, each for a period of 20 years (175,000 hours), using as input the chain of the random values from each row. Each row from the input Excel spreadsheet includes the input data for the corresponding scenario. This model's output will be the average Ao for each scenario and will be written to the previous Excel spreadsheet in a new column (average Ao output value, Figure 6, Column N). Moreover, the average Ao outputs for each scenario will give the authors a distribution of Ao values. Using statistics and Excel software, the authors can extract the descriptive statistics data for the Ao's distribution, and then determine the readiness risk.

scenario	Λ1	Λ2	Λ3	Λ4	Λ5	# spare 1	# spare 2	# spare 3	# spare 4	# spare 5	3rd echelon TAT	4th echelon TAT	OP_Temp	Ao	Life Cycle Cost
1	0.00562	0.008403	0.002083	0.00256	0.002967	7	5	5	7	7	7	70	615	0.550	$102,158,111
2	0.00469	0.009615	0.002174	0.00275	0.003125	5	6	3	6	6	5	61	580	0.601	$96,051,308
3	0.00461	0.007937	0.00241	0.00275	0.002793	6	7	6	6	8	7	48	490	0.756	$80,543,809
4	0.00493	0.007092	0.002101	0.00275	0.003058	4	7	6	5	5	10	51	516	0.670	$82,558,230
5	0.00488	0.00813	0.002092	0.0026	0.003226	7	3	4	8	6	8	61	438	0.701	$71,957,223
6	0.00474	0.00885	0.002137	0.00265	0.003195	5	6	6	6	4	7	64	594	0.560	$97,112,656
7	0.00493	0.011111	0.002096	0.00265	0.002688	6	2	3	7	6	3	63	569	0.612	$95,852,645
8	0.00529	0.009174	0.002183	0.00268	0.003058	3	5	3	7	4	8	56	588	0.587	$97,811,305
9	0.00515	0.009615	0.002315	0.00258	0.002874	7	6	10	1	9	8	60	490	0.648	$83,213,655
10	0.00541	0.009091	0.002119	0.00259	0.002976	4	6	6	7	9	8	52	542	0.672	$90,606,866
11	0.00546	0.00813	0.001976	0.00275	0.003257	5	4	6	3	5	4	57	448	0.646	$73,776,606
12	0.00515	0.00885	0.001996	0.0024	0.003289	5	5	6	6	3	8	67	472	0.601	$77,670,958
13	0.00521	0.008547	0.002083	0.00267	0.002994	3	6	2	3	7	6	31	444	0.815	$72,776,212
14	0.00581	0.008065	0.00241	0.00268	0.002967	6	4	5	5	6	6	47	555	0.670	$93,976,117
15	0.00526	0.00813	0.002188	0.00256	0.003077	8	6	6	5	6	12	48	607	0.647	$100,263,742
16	0.00508	0.007813	0.001946	0.0026	0.003205	5	8	7	6	5	7	65	536	0.591	$86,571,551
17	0.00515	0.010417	0.002179	0.00268	0.002817	6	3	3	7	7	7	42	419	0.797	$71,574,112
18	0.00524	0.01	0.002188	0.00262	0.003135	2	6	4	3	11	8	66	598	0.542	$100,493,845
19	0.00513	0.009259	0.002058	0.00259	0.00304	6	9	9	4	5	12	76	474	0.567	$79,113,750
20	0.00505	0.009615	0.002217	0.0025	0.002959	6	7	5	5	7	4	72	479	0.621	$80,586,739
21	0.00521	0.00885	0.002123	0.00261	0.002755	9	7	5	5	4	9	52	610	0.641	$100,951,389
22	0.00513	0.009346	0.002075	0.00255	0.00289	5	6	5	3	6	6	59	548	0.604	$90,404,166
23	0.00543	0.009615	0.002227	0.00262	0.003049	7	7	3	6	6	11	75	540	0.558	$91,966,044

Figure 6. A Screen Shot of Excel Input-Output Spreadsheet

2. Excel Spreadsheet Model

The Excel spreadsheet model is an Excel spreadsheet that computes the operational and support (O&S) cost. The original model was first used for the unmanned air vehicle (UAV) case study[10] by Prof. Keebom Kang and is described in the Logistics Engineering (GB 4410) class lecture notes at the Naval Postgraduate School, CA (Kang, 2010). The Excel spreadsheet model uses as inputs the number of weapon systems, life cycle period, hourly operating cost, hourly repair cost, transportation cost per failure, annual discount rate, the annual spare parts usage rate, and the unit cost of each component. These inputs are used only in the Excel spreadsheet model (depicted in yellow in Figure 7). Additionally, it uses as inputs the component's failure rate, the average TAT, the number of spares in the inventory pool, and the Op-Tempo. These inputs are used also in the Arena model (depicted in green in Figure 7).

A visual basic macro program was provided by Kang et al. (2009) to calculate the LCC for each of the 257 scenarios. Once the macro is executed, it reads the input parameters for each scenario. The calculated LCC for the current scenario is extracted in the Excel spreadsheet (cell A35 in Figure 7). Before executing the next scenario, the calculated LCC is copied in the respective Arena Excel spreadsheet (column O in Figure 6).

Using the output data from the LCC column, the descriptive statistics data for the LCC (e.g., the average LCC and its standard deviation for each case) can be extracted, and the relationships between LCC, Ao, readiness risk and the other input factors' values can be identified.

D. DATA GATHERING

The collecting data for LAV-25 components' average failure rate (λ), unit cost, identification of critical and non-critical components, and source maintenance and recoverability (SMR) code, which determines the echelon of

[10] UAV case study by Prof. Keebom Kang, (Kang, 2010).

maintenance, were adopted from *MCDSS*[11] *4.3.11, Part Usage EO974* (2007-2009). The rest of the data was collected from telephone calls, electronic mails (e-mail), and note taking.

In the case of the absence of actual data and in order to apply the models to current LAV-25 systems, the authors used estimated data or value ranges, especially for the number of spares in inventory, the echelon turnaround time (TAT), and Op-Tempo. Additionally, estimated data were used for the hourly operating cost, hourly repair cost, transportation cost per failure, annual discount rate, and the annual spare parts usage rate, These estimations remained the same in all cases so that a common base of cost comparison between the cases could be established.

[11]MCDSS: Marine Corps Decision Support System. Automated decision support system (logistics information systems) designed to support Logistic Command (LogCom) logistics managers, from the IM to the commander in strategic logistics decision-making processes. It provides data extracts from maintenance, inventory, and finance systems to perform decision support of the master work schedule planning and Depot Level Maintenance Program (DLMP) activities.

Life Cycle	1	
# LAVs	76	
Operating hrs	432	hrs/year
Protection Level for Critical Components	0.95	
Protection Level for non-Critical Components	0.85	
Operating cost/ hr	$100	
hourly charge for repair including material cost	$300	
Trasportation per failure	$200	
Annual Inventory rate	20%	
Capital Discount rate	7%	
Life Cycle	20	years

LAV-25 O&M Life Cycle Cost Estimation

Ground Control Station Components	failure rate per day	λ (failure rate per op hr)	Unit Cost		Protection Level	# of units per sys-tem	# of units per MEF	Average Repair Turnarou nd	Op Hr during TAT	k*λ*t Avg Failures during TAT	Requred spares (Using Poisson)	Required spares (Using Poisson)	Tot Spare cost	Annualized spare cost	Failures/ System /yr	Tot no of failures per yr per MEF	Avg repair time (hrs)	Tot num of for reapir hrs	Tot repair cost	Traspotation Cost
SENSOR UNIT,LASER DE	0.00021164	0.00535	$89,794	Critical	0.95	2	152	51	60.4	49.06		7	$628,560	$125,712	2.3	351	10	3511	1,053,433	70,229
CONTROL DISPLAY UNI	0.00036331	0.00901	$27,683	Critical	0.95	1	76	6	7.1	4.86		3	$83,050	$16,610	3.9	296	10	2958	887,351	59,157
DIFFERENTIAL,DRIVING	8.9064E-05	0.00236	$22,475	Critical	0.95	4	304	6	7.1	5.10		8	$179,800	$35,960	1.0	310	10	3105	931,404	62,094
ENGINE,DIESEL	0.00010935	0.00273	$41,757	Critical	0.95	1	76	51	60.4	12.53		4	$167,027	$33,405	1.2	90	10	897	269,115	17,941
Engine, Diesel	0.00012698	0.00329	$26,890	Critical	0.95	1	76	51	60.4	15.09		6	$161,341	$32,268	1.4	108	10	1080	324,000	21,600
													$1,219,778	**$243,956**					**3,465,304**	**231,020**

Total Logistics cost per MEF per year	**$3,709,259**	per year
Opeating cost per MEF per year	**$3,283,200**	per year
Total Annual cost	**$6,992,459**	
$74,078,213	**Life Cycle Cost**	

Figure 7. A Screen Shot of the LCC Excel Spreadsheet Model (After: Kang et al., 2009)

E. LIMITATIONS

The accuracy of the Arena simulation and LCC Excel spreadsheet model calculations are only as good as the input data provided. If actual data can be retrieved for every input factor, the Ao, readiness risk and LCC will be a true calculation. When the data provided are estimated or assumed, the models then only provide the best possible results. For the Arena model the inputs become a limitation as only this data is used strictly by the model to calculate Ao and readiness risk. The current set up of the model allows only the components failure rate (λ_i) input of the five components of the LAV-25 If the model was developed to include all the components' λ_i, then a more accurate assessment of the actual Ao and readiness risk could be determined.

F. APPLICATION

These models can be used on any weapon system if the data can be retrieved. By making minor changes to the model (system components, etc.), the model may be applied to many weapon systems currently in use throughout the Department of Defense (DoD), such as the Mine Resistant Ambush Protected (MRAP) Vehicle, and aircraft such as the F-22 or F-35.

This model allows the warfighters and logistics teams to decide which of the Ao's synthetic parameters are more sensitive to maintain specific levels of Ao and readiness risk in conjunction with the cost and the logistics or operational constraints (i.e., number of spares in the inventory, maintenance TAT, Op-Tempo). Warfighters and logistics teams can suggest alternative maintenance policies that will have impact on desired maintainability, supportability, and finally on Ao and readiness risk.

Lastly, it equips the PMs and contracting officers with the ability to make better sound judgments if a proposal by a contractor is being offered, and ensures that a cost-effective and reliable weapon system will be available for the warfighters. In the early phase of an acquisition, an initial Ao threshold as a key performance parameter (KPP) is created to support mission requirements.

IV. LOGISTIC IMPACT INTO ACQUISITION MANAGEMENT

A. INTEGRATED DEFENSE ACQUISITION, TECHNOLOGY, AND LOGISTICS LIFE CYCLE MANAGEMENT SYSTEM

Logistics is a crucial component in the contemporary acquisition process. Logistics are involved in all phases of the acquisition framework, from the definition of the requirement to the disposal of the system. In major weapon systems, the main impact of logistics is during the operation and support phase, otherwise known as the sustainment phase. However, it is of great importance for the life cycle management and total ownership cost how effectively and efficiently the issues of mission supportability and overall support capability are addressed during the design and development phases.

The life cycle logistics for the acquisition of weapon systems is defined by the Defense Acquisition University as

> the planning, development, implementation, and management of a comprehensive, affordable, and effective systems support strategy within Total Life Cycle Systems Management (TLCSM). Life cycle logistics encompasses the entire system's life cycle including acquisition (design, develop, test, produce, and deploy), sustainment (operations and support), and disposal. The principal goals/objectives of acquisition logisticians are to:
>
> 1. Influence product design for affordable system operational effectiveness.
>
> 2. Design and develop the support system utilizing performance based logistics.
>
> 3. Acquire and concurrently deploy the supportable system, including support infrastructure.
>
> 4. Maintain/improve readiness, improve affordability, and minimize logistics footprint. (*Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System Chart*, 2009)

The life cycle logistics overview in relation with the integrated defense acquisition, technology, and logistics life cycle management system is presented in Figure 8.

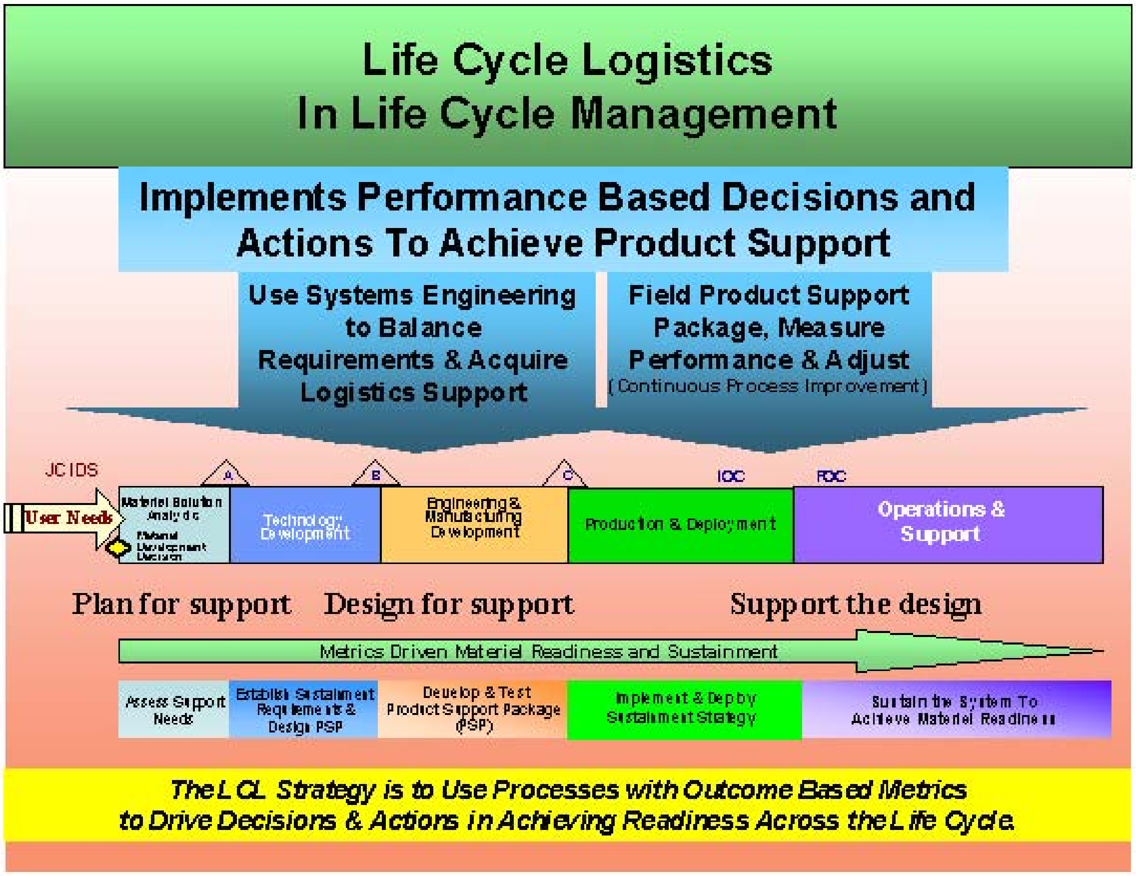


Figure 8. Life Cycle Logistics Overview (From: *Defense Acquisition Guidebook*, 2010)

The *DoD Directive 5000.01* (2003) mandates that “acquisition programs shall be managed through the application of a systems engineering approach that optimizes total system performance and minimizes total ownership costs.” Furthermore, supportability and life cycle costs are important parameters for the acquisition. Program managers have to follow a total systems approach and are held accountable for the life cycle systems management, including sustainment of objectives.

> Planning for Operation and Support and the estimation of total ownership costs shall begin as early as possible. Supportability, a key component of performance, shall be considered throughout the system life cycle. (Department of Defense, 2003, p. 10)
>
> According to the *Defense Acquisition Guidebook* (2010), consideration should be given to the effects that the various acquisition decisions will have on life cycle management. A key concept of life cycle management is "supportability and maintainability as key elements of performance" (Department of Defense, 2003, p. 148). It includes:

- "Performance-based strategies, including logistics
- Increased reliability, improved maintainability, and reduced logistics footprint
- Continuing reviews of sustainment strategies" (Department of Defense, 2003, p.148)

Supportive to the policy established by DoD Directive 5000.01 is the *Memorandum for Secretaries of the Military Services from the Under Secretary of Defense (AT&L)*, signed on July 31, 2008. The memorandum with subject "Implementing a Life Cycle Management Framework" underlines that this implementation is a top DoD priority. It also sets up a strategy and provides directions for the following:

- "Reinforce the implementation of mandatory life cycle sustainment metrics
- Align resources to achieve readiness level
- Track performance throughout the life cycle
- Implement performance-based life cycle product support strategies" (Department of Defense, 2003 p. 1).

The memorandum mandates the establishment of target goals for the mandatory metrics for life cycle sustainment. Those metrics, as set by the *Chairman of the Joint Chiefs of Staff Instruction 3170.01F* (2007), are availability as the sustainment key performance parameter and reliability and ownership cost

as key system attributes (KSAs)[12]. Most importantly the memorandum mandates the use of modeling and simulation tools for analyzing and assessing readiness, as well as key life sustainment metrics.

The most recent document enforcing life cycle management and focusing on the improvement of logistics is the *Quadrennial Defense Review* (QDR) as of February 12, 2010. More specifically, the QDR addresses the issue of how to improve the execution of acquisition programs and, among others, designates to "achieve effective life cycle cost management by employing readiness-based sustainment strategies, facilitated by stable and robust government-industry partnerships" (Secretary of Defense, 2010, p. 79).

Earlier QDRs introduced the concern about the impact of logistics in the life cycle of a weapon system. The QDR of 2001 put forth the initiative for the DoD to "implement Performance-Based Logistics to compress the supply chain and improve readiness for major weapons systems and commodities" (p. 56). As a result, the DoD tried to reduce the logistic footprint and the related costs (Secretary of Defense, 2006). The QDR of 2006 focused on "improving visibility into supply chain logistics costs and performance and on building a foundation for continuous improvements in performance" (p. 72) In addition, it recognized and directed that various promising initiatives and insights should be "coupled with the implementation of continuous process improvement tools like Lean, Six Sigma and performance based logistics" for optimizing "the productive output of the overall Department of Defense supply chain" (Secretary of Defense, 2006, p. 72).

[12] Key system attribute (KSA): An attribute or characteristic considered crucial in the support of achieving a balanced solution/approach to a key performance parameter (KPP) or some other key performance attribute deemed necessary by the sponsor. KSAs provide decision makers with an additional level of capability performance characteristics below the KPP level and require a sponsor 4-star , Defense Agency commander, or Principal Staff Assistant to change (Chairman of the Joint Chiefs of Staff, 2007).

All aforementioned policies and directions recognize the need for a life cycle management approach and the implementation of life cycle logistics from the early stages of the acquisition process. The main tool that policies and directions designate is performance-based logistics, which will be discussed in the following section.

B. PERFORMANCE-BASED LOGISTICS

Performance-based logistics (PBL), as defined in the *Glossary of Defense Acquisition Acronyms & Terms* (2005) is

> the preferred sustainment strategy for weapon system product support that employs the purchase of support as an integrated, affordable performance package designed to optimize system readiness. PBL meets performance goals for a weapon system through a support structure based on long-term performance agreements with clear lines of authority and responsibility. (p. B-102)

In plain language, the DoD is buying performance and readiness, instead of buying for a specific good or service. The main goals of PBL are to reduce the supply chain, reduce the TOC, and improve the readiness of weapon systems. The greatest impact of logistics in TOC is during the operational and support phase (or sustainment phase), where most of the costs are incurred.

The QDR of 2001 advocated the implementation of PBL with the appropriate metrics. As a result, in *DoD Directive 5000.01* (2007), which "provides management principles and mandatory policies and procedures for managing all acquisition programs," PBL was mandated as policy. Accordingly,

> PMs shall develop and implement performance-based logistics strategies that optimize total system availability while minimizing cost and logistics footprint. Trade-off decisions involving cost, useful service, and effectiveness shall consider corrosion prevention and mitigation. Sustainment strategies shall include the best use of public and private sector capabilities through government/industry partnering initiatives, in accordance with statutory requirements. (p. 7)

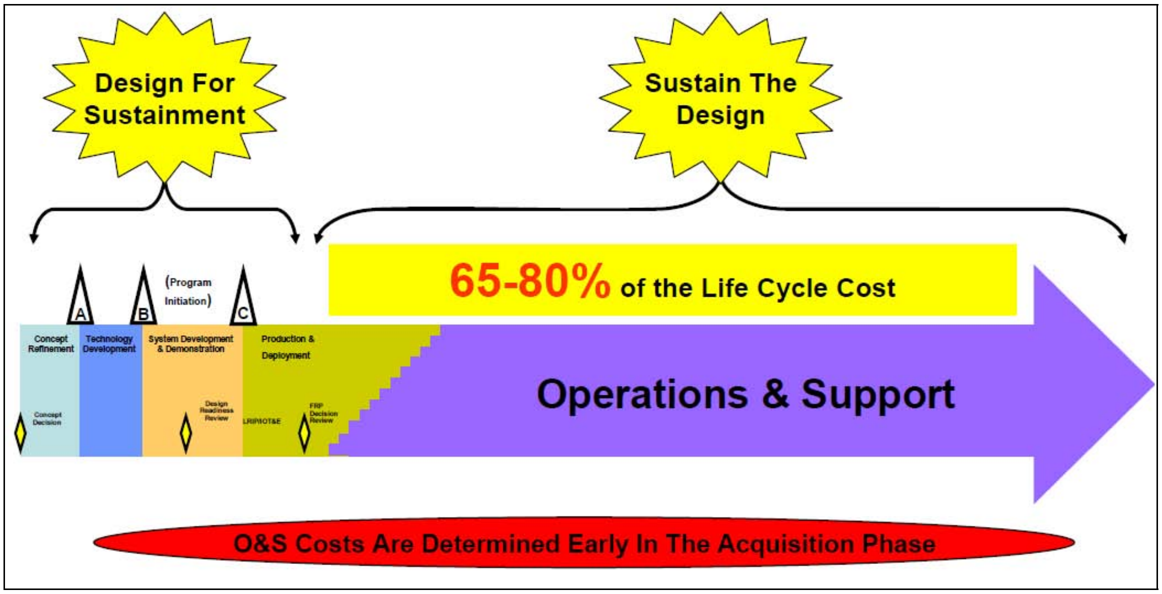


Figure 9. Total Ownership Cost (From: Hardy, 2007)

An aggressive effort to implement PBL was mandated by Deputy Secretary of Defense, Mr. Paul Wolfowitz (2004). PBL has been designated as a "best business practice," thus all services were directed to implement PBL on any "current and planned weapon system platforms" (Deputy Secretary of Defense, 2004, p. 1). Availability and readiness should be the purchased by DoD products, as measured by the appropriate performance criteria (Deputy Secretary of Defense, 2004).

In the Under Secretary of Defense (AT&L) *Memorandum* of November 2005, TLCSM metrics were established. Those six metrics are used to measure the performance of PBL and are the following:

- Operational availability
- Mission reliability
- Total life cycle system cost per unit of usage
- Cost per unit of usage
- Logistics footprint
- Logistics response time

The definitions and formulas of metrics given in the memorandum do not vary from the definitions and formulas for the above that are used for this project, as given in Chapter II. Also, they do not differentiate from the metrics described in the *Performance Based Logistics: a Program Manager’s Product Support Guide* (2005). The same memorandum (USD (AT&L), 2005) directs the TLCSM executive council to develop a “TLCSM metrics handbook,” a task that has not been accomplished up to date.

The *Performance Based Logistics: a Product Manager's Product Support Guide* (2005) sponsors the use of long-term, fixed price with incentives, contracts. The metrics should be linked to the contract incentives that each military department establishes. Furthermore, the metrics, their definition, and the period of performance should be clearly defined in PBL contracts. The incentives are important in PBL contracts as the risk is more on the side of the contractor providing the agreed performance and support. Nonetheless, it is the agency’s responsibility to appropriately weigh the metrics and identify the strategy that will have the desired outcomes.

In the same guide it is also designated that

> The PBL application will meet the warfighter’s operational requirements and be cost-effective as validated by a Business Case Analysis[13] (BCA). PBL utilizes a performance based acquisition strategy that is developed, refined, and implemented during the systems acquisition process for new programs or as a result of an assessment of performance and support alternatives for fielded systems. PBL can help PMs optimize performance and cost objectives through the strategic implementation of varying degrees of government-industry partnerships. (*Performance Based Logistics: A Product Manager's Product Support Guide*, 2005. p. 2-3)

[13] Business case Analysis (BCA): A PBL BCA is an expanded cost/benefit analysis created with the intent of determining a best-value solution for product support. Alternatives weigh total costs against total benefits to arrive at the optimum solution. The PBL BCA process goes beyond cost/benefit or traditional economic analyses by linking each alternative to how it fulfills strategic objectives of the program; how it complies with product support performance measures; and the resulting impact on stakeholders. A PBL BCA is a tailored process driven by the dynamics of the pending investment decision to adopt a PBL strategy (*Performance Based Logistics: A Product Manager's Product Support Guide*, 2005).

PBL has been used in many major weapon system acquisitions since its introduction in the early 1990s (General Accountability Office, 2004). PBL has been used in both platform and subsystem or component levels. Table 2 lists some of the major weapon systems that implemented PBL (*Product Support for the 21st Century: a Program Manager's Guide to Buying Performance*, 2001), (*Performance Based Logistics: A Product Manager's Product Support Guide*, 2005), (Government Accountability Office, 2008). The first document providing detailed guidance for the implementation of PBL was the *Product Support for the 21st Century: a Program Manager's Guide to Buying Performance* (2001), commonly known as "The PBL Guide." This document not only provided PBL guidance but introduced DoD's Reduction in TOC (R-TOC) program for selected weapon systems. This document was superseded in 2005 by the *Performance Based Logistics: a Product Manager's Product Support Guide*.

There is a lot of discussion regarding the effectiveness of the implementation in relation to the objectives. The GAO report of 2004 reviewed "DoD's process of implementing PBL as the preferred support strategy for its weapon system" (Government Accountability Office, 2004). The findings were that the DoD's recommendation was for PBL application at the weapon platform level, as the one used for T-45 Navy training aircraft, rather than the component level. However, the GAO found that most of the 185 PBL programs that were identified for the purposes of the report were at a subsystem or component level. Moreover, the GAO found that the private sector industry with same life cycle management and TOC concerns differ in their approach regarding PBL. They use it as a tool rather than as a concept approach, and almost exclusively at a subsystem or component level. On the other hand, the companies examined in the report were relying more on time and material contracts. Time and material contracts is a high-risk approach that the DoD prefers to avoid (*Federal Acquisition Regulation*, 2005).

Army	Consolidated automated support system	Air Force
Tube-launched optically-tracked wire-guided missile – Improved target acquisition system	T-45 engine	F-16 engines
Javelin antitank missile	KC-130J	T-6A Joint primary air training system
High mobility artillery rocket system	V-22 engine	F-117A Nighthawk
RQ-7B Shadow tactical unmanned aircraft system	Phalanx close-In weapon system	F-22 Raptor
Sentinel radar	F-404 Engine	B-2 Spirit
Patriot air defense system	Auxiliary power units (APU)	Secondary power systems
AH-64D Apache helicopter - Sensors	AEGIS Cruiser	E8-C Joint surveillance target attack radar system
AH-D64D Apache helicopter – Airframe	CVN-68	LITENING Advanced airborne targeting and navigation pod
AN/TSQ-179AV(2) Common ground station	LPD-17	Sniper advanced targeting pod
Abrams M-1 Tank	H-60 series helicopters	C-130J Hercules
Chinook CH-47	Standoff land attack missile – Expanded response	C-17 Globemaster
Guardrail / Common sensor	Advanced amphibious assault vehicle	C-5 Galaxy
Navy	Aircraft tires	E-3A AWACS
Crusader	**Marine Corps**	C/KC 135 Stratotanker
ALR-67 (V3)	Expeditionary fighting vehicle	
AV-8B Harrier	Assault breacher vehicle	

Table 2. PBL Supported Weapon System Programs [After: (Product Support for the 21st Century: a Program Manager's Guide to Buying Performance, 2001), (Performance Based Logistics: A Product Manager's Product Support Guide, 2005), (Government Accountability Office, 2008)]

In conclusion, the GAO recommended using PBL as "a tool to achieve economies at the subsystem or component level" (Government Accountability Office, 2004, p. 20). The DoD concurred with the recommendation.

The *Performance Based Logistics: a Program Manager's Product Support Guide* (2005), incorporates examples of PBL programs that characterizes them as successful. Among them are the weapon systems chosen as pilots for the R-TOC program. According to the guide the PBL implementation for the R-TOC program "has been highly successful, reaping significant cost savings / avoidance and identifying leassons learned" (p. 5-7). The projected savings from 1997 to 2005 was expected to exceed $1.3 billion (Pallas, 2002), as presented in Figure 10.

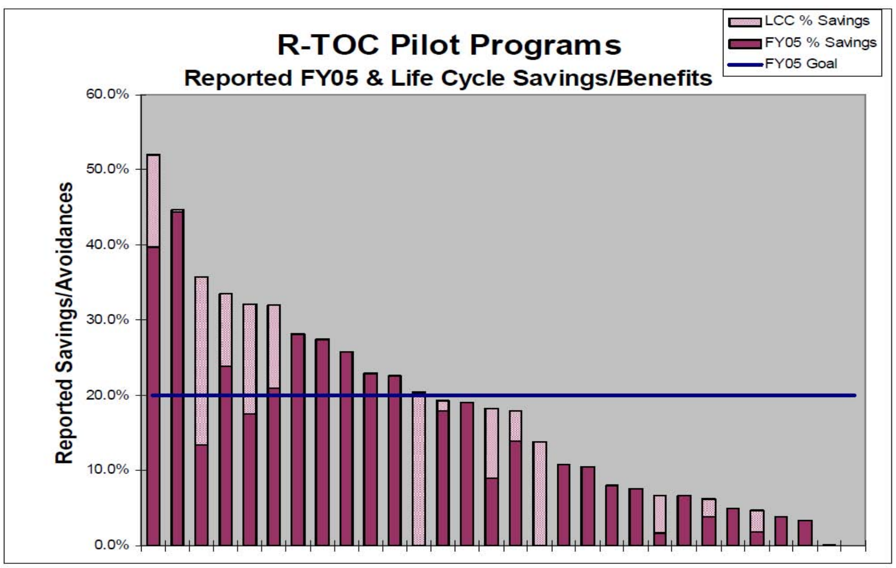


Figure 10. R-TOC Pilot Programs Savings/Benefits (From: Pallas, 2002)

In a report published later in 2005, the GAO found that the DoD did not demonstrate any benefits from the PBL programs that the GAO reviewed. That was because the respective program offices did not update the business case analysis (BCA) as the *Performance Based Logistics: a Product Manager's Product Support Guide* (2005) directs. In the only case, out of the fifteen reviewed, that BCA was updated the results showed that the PBL contract "did

not result in the expected cost savings and the weapon system did not meet established performance requirements" (Governement Accountability Office, 2005, p. 3) The main reason for not updating BCAs was that program offices assumed that in any case the fixed-price PBL contracts would be less costly than the traditionnal contracts. However, the findings of the review on the single program that did the BCA, namely the T-45 Navy training aircraft, are particularly interesting for the purposes of this MBA report. The T-45 program office updated the BCA on the fact that the contractor could not meet the aircraft availability performance metric. This incurred more cost per flying hours than it was estimated. The program office then re-negotiated new contracts in a subsystem level for airframes and engines. The estimated cost savings of these new contracts were $144 million over five years. For the history, the GAO suggested that the USD (AT&L) should reaffirm guidance for the BCA update, and better direct PBL contractor performance as well as the involvement of the Defense Contract Management Agency (DCMA) and Defense Contract Audit Agency (DCAA). The DoD concurred with the GAO's recommendations.

The latest GAO report regarding PBL was published in December 2008. The findings were that the GAO's perspective on the ability of PBL to reduce TOC was unclear. According to the report, BCAs "have not been used consistently or effectively to influence decision making regarding PBL" (Government Accountability Office, 2008, p. 14). The main reason was that BCAs were not appropriately updated or the provided data were not adequate to come to a safe conclusion regarding the benefits of PBL and the accomplishment of objectives. Furthermore, the GAO identified that the DoD has put more emphasis on the improvement of performance than the reduction of support and TOC. Other significant findings were that PBL constructions often included short term contracts, unstable program requirements and funding, and lack of cost metrics and/or cost reduction incentives. The GAO considers that such construction characteristics reduce the potential for TOC reduction. In order to draw useful insight, the GAO examined and made a comparison with

arrangements similar to PBL, called availability contracts, which the United Kingdom Ministry of Defense (UK MOD) uses. The main points of the comparison is that the UK MOD uses arrangements similar to PBL to support subsystems and equipment rather than entire weapon systems, the respective contracts are significantly longer than those of the DoD, and they constantly update the respective BCAs to oversee contractors and control costs. According to the UK MOD, those availability contracts have met the objectives and have been beneficial. Besides, private industry is interested in being involved in long-term contracts for such programs. The GAO recommended making BCA a required step before awarding a PBL contract, as well as during the PBL contract, and having clear guidance on how to use BCAs in the decision-making process. The DoD concurred with the recommendations but disagreed with the GAO's claim that the goal of PBL is to reduce cost. DoD noted that "the primary goal of PBL arrangements is to increase readiness and availability while reducing overall sustainment costs in the long run" (Government Accountability Office, 2008).

Despite the GAO's 2008 report, a few months earlier in the "2008 Department of Defense Maintenance Symposium & Exhibition" all speakers representing the DoD, military agencies, and industry agreed on the success of PBL programs (Anderson, 2008), (Diaz, 2008), (Klevan, 2008), (Fowler, 2008). Substantial cost and performance benefits were presented by the Assistant Deputy Under Secretary of Defense for Material Readiness (Fowler, 2008). These are presented in Tables 3 and 4. However, no references regarding concerns and negative aspects, if any, were given.

In a recent article published in *Overhaul & Maintenance* magazine (April 2010, under the title "PBL pressure points" (Ott, 2010), the Assistant Deputy Under Secretary of Defense Randy Fowler argues in favor of PBL programs, asserting that PBL programs have "demonstrated success." He recognizes that there are issues and there should be improvement in problematic areas after "fact-based analysis." For that reason, a new generation of PBL is currently

being developed. Mr. Fowler identifies “system availability and readiness” as a metric of PBL goal achievement. Key officials of private industry involved with PBL, such as General Electric Aviation, Boeing, and Raytheon agree that PBL is successful and beneficial for all parties. However, they all identify the need for improvement in areas such as determination by the agency of the required performance and the increase of competition.

Defense-oriented private sector companies are not the only companies recognizing the significance and potentials of PBL. It is also recognized as a sound business-to business practice by the rest of the industry. In the article “*Vested Outsourcing: a Better Way to Outsource* (2009),” based on research conducted with the University of Tennessee and the United Air Force, the authors analyze the conclusions of the research and describe the benefits of a practice almost identical to PBL, which they name vested outsourcing. Vested outsourcing buys outcomes, not individual transactions. The outcomes should be quantifiable and of different types such as availability, reliability, cost, revenue generation, and employee or customer satisfaction. Metrics should be defined and ideally should be no more than five. Also, other elements and details of this kind of approach are described. Presenting examples of vested outsourcing the authors discussed the DoD’s PBL and claimed that the research they conducted demonstrated a lot of success stories among over 200 DoD PBL examples.

Program	Availability Benefits
F/A-18	+23%; 98% RFT
F/A-18 SMS	+32%
H-60 Avionics	+14%
Navy Tires	+17%
AEGIS	+30%
F-404 Engine	+46%
T-700	+35%
CIWS	+9%
Mk41 VLS	+8%
Sea Sparrow	+14%
Navy Spt Equip	+32%
Nimrod (UK)	+40%
AN/ALQ-126B	+50%
AN/USM-638	+40%
LANTRIN	+17%
EA-6B Flt Cont	+47%
F-22	+15% MC

Program	Availability Benefits
B-2	47.2% MC (Record Level)
E-8	99.5% Lch Rt; 97.6% ME
ALR-67(v)3	97% Avail
Sentinel	95% Avail
Shadow	
TAIS	96%+ OR
Javelin	98%+ Avail
ITAS	99%+ OR
CGS	99% Avail
HIMARS	98.7% Avail
C-17	93.5% Dpt Rel; 85.4% MC
C-17 Engines	70% TOW incr
T56-15 Engines	+35% TOW
APS-137	+40% TOW
AN/PPS-14	95% Eff. Rate
F-414 Engine	97% Avail

Program	Cycle Time Benefits
F/A-18	-74% LRT; -33% RTAT
F/A-18 SMS	-84% LRT
H-60 Avionics	-85% LRT
Navy Tires	-92% LRT; -100% B/O’s
APUs	-82% LRT
LANTRIN	-90% LRT
F-404 Engine	-25% RTAT
T-700	-74% RTAT; -100% B/O’s
AH-64 Apache	-35% RTAT
Pegasus Engine	-59% RTAT
CH-47 (UK)	-44% RTAT
F-22	-20% RTAT
B-2	-20% RTAT (Depot)
CIWS	-99% B/O’s
Sea Sparrow	-90% B/O’s
F-404	-66% B/O’s
Patriot	-99% B/O’s
RFTLTS	-96% B/O’s

RFT: Ready for Tasking; MC: Mission Capable; OR: Operational Readiness; ME: Mission Effectiveness; TOW: Time-on-Wing; B/O’s: Backorders; LRT: Logistics Response Time; RTAT: Repair Turnaround Time

Table 3. PBL Availability Benefits (After: Fowler, 2008)

Program	Total Cost Benefit ($M)
F-22	$14,000
ALR-67(v)3	$62.7 (40%)
TOW-ITAS	$350
F/A-18	$688
CGS	$10.3 (65%)
MIDs-LVT	$62 (54%)
AN/AAS-44	$31 (25.2%)
APUs	$4 (20.9%)
AEGIS FCS	$8 (19.3%)
F-405 Engine	$61 (17.2%)
Cockpit Disp.	$71 (16.5%)
F-100	$2 (16.3%)
AH-64 & CCAD	$100
CH-47 (UK)	$250
Javelin	10%
RFTLTS	$0.5

Program	Total Cost Benefit ($M)
ARC-210	$5.4 (8.6%)
TH-57	$15.3 (7.9%)
H-60	$41 (6.5%)
Sea Sparrow	$2.2 (6.3%)
AN/WSN-7	$0.88 (1.3%)
AN-PSS14	$17
Sentinel	$301.7
T-45	$85
C-17	$477
Navy Spt Equip	$1
AN/ALQ-126B	$2.1
AN/USM-638	$0.5
C-17	59%
Tornado (UK)	51%
Harrier (UK)	44%
Nimrod (UK)	8%

Program	Annual Cost Benefit ($M)
F-22	$500 (39%)
CASS CSP	$30 (54%)
TOW-ITAS	$6.3 (34.5%)
ARCI	$4 (24.7%)
Mk41 VLS	$1.1 (16.4%)
F-117	$124 (14.5%)
Navy Tires	$46 (15%)
GBMD	$1.6
TAIS	$0.01
H-46	$0.35
Program	**Flying Hour Cost Reduction**
LANTRIN	$9.6 (14.6%)
F-404 Engine	$79 (13.4%)
F-414 Engine	$6.4
Patriot	$1 (13.1%)

Table 4. PBL Cost Benefit (After: Fowler, 2008)

C. THE ROLE OF MODELING AND SIMULATION IN PBL/ LAV-25 CASE

The discussion and analysis on the DoD indicates that PBL would achieve better results if it was implemented at a subsystem or component level. However, what really matters to the warfighter is the operational availability of the weapon system (Kang, Doerr, Boudreau, & Apte, 2005). Evidently, the expected outcomes of component levels should be linked and their compound effect in the weapon system and the attributes that are of great concern for the warfighter should be determined. This can be achieved by using modeling and simulation (M&S). The warfighter, as well as the decision makers in various tiers of command, such as the base command level (expeditionary force), major command level, and acquisition authority level, can utilize the integrated outcome of an M&S model to make decisions throughout the entire spectrum of the life cycle framework. In *Designing and Assessing Supportability in DoD Weapon Systems: a Guide to Increased Reliability and Reduced Logistics Footprint* (2003), it is indicated that M&S should be "vigorously applied" in the acquisition process.

As the complexity of systems and at the same time the complexity of the desired outcomes increase, the call for a tool that will provide the warfighter with the "big picture", incorporating crucial for the mission elements, is getting bigger. The DoD's objectives are complex, related to the mission, and differ from the objectives of the business world (return on investment, profit, etc). Thus, it is difficult for a decision maker to evaluate all inputs, parameters, and risks to make a sound decision. As Doerr, Eaton, and Lewis (2005) point out,

> unless decision makers have comprehensive models of weapon-systems logistics, (in which the important performance dimensions of all critical components are modeled), they cannot value a component-level contract in terms of system-level outcomes like operational availability. (p. 228)

The same research also finds that there is a need for DoD "to require comprehensive system-level models to value and price component-level contracts, and evaluate component-level logistics-service provider performance" (Doerr et al., 2005).

The DoD's objectives are different than private businesses' goals, as the incentives are totally different. Although the outcome of the mission is probably the most significant objective, the cost to achieve the outcome is of high importance as well. Resources are limited and have to be spread among many diverse requirements. Thus, the M&S should be applied in a way that will provide helpful insight for both the performance and TOC. In the basic elements of M&S the essential metrics of PBL should be addressed. The desired results should be in terms of performance, such as Ao, and how they impact TOC.

Models in PBL can be used for both existing and future systems to support BCAs. In existing systems, PBL can be utilized to evaluate proposed changes for improvements in relation with the desired outcome, which may differ in different situations. In future systems, PBL can be utilized in the design of the system and help to define trade-offs in man-power, reliability, availability, maintainability, and alternate maintenance concepts and their effects on supportability (Office of Secretary of Defense, 2003). Also, PBL can be used to identify the requirements of logistic resources, forecast readiness, and can determine the optimum mix of spare parts and maintenance. Furthermore, PBL can assist decisions regarding the trade-off between TOC and Ao.

In Chapter II, the importance of Ao as a performance measure was discussed. Ao is the most important metric for PBL implementation. Concurrently, readiness risk (the probability that Ao will be achieved) was discussed. Readiness risk is important for decision-making purposes. Accordingly, it should be an element of a simulation model regarding life cycle management. The model should indicate how changes in the required readiness risk impact TOC.

This project adapts two models from Kang et al. (2009)–-an Arena simulation model and an Excel spreadsheet model–-for studying the LAV-25 case. The inputs are subsystem factors while the outcomes are Ao, readiness risk, and the impact in TOC, with the assumptions discussed in Chapter III. TOC in the LAV-25 study case is essentially the total LCC that this project has used, as was explained in Chapter II. In case four, the model keeps the following factors stable: turnaround time (TAT), number of spares in the spare inventory, and Op-Tempo; the authors then change the failure rates λ of the components that were identified by this project as the most critical ones. In case five, the model keeps the following factors stable: number of spares in the spare inventory and Op-Tempo; this time, the authors change the failure rates λ of the components and turnaround time (TAT). Actually, cases four and five are the investigation of different alternatives for potential PBL contracts regarding those components. Various levels of Ao and readiness risk will indicate the required failure rate. The impact on TOC could help the decision maker to evaluate the trade-offs between performance and cost, and drive the decisions for PBL agreements. This particular case, as a study, is discussed in two parts (cases four and five) that are described in the following chapter.

D. CONCLUSION

The total ownership cost of weapon systems is currently a point of great concern for the DoD. A total life cycle systems management approach has been directed in order to optimize the performance of a system, and the same time minimize TOC. Logistics have a great contribution to TOC especially in the sustainment phase of a system’s life cycle. PBL has been identified by the DoD as a tool that will help control and minimize the logistics impact in TOC, providing the desired performance while reducing costs.

Performance-based logistics focuses on the outcome, rather than how to achieve the desired outcome. This approach makes the acquisition process more agile. PBL has been implemented in over 200 weapon system programs in

at a system, subsystem, or component level. In many of those programs, some substantial benefits have been recorded. Private industry seems to embrace PBL as a business practice, and except for the DoD acquisitions, is implementing it into business-to-business acquisitions. PBL can be implemented in both legacy and new design systems. The DoD explicitly indicates that “the primary goal of PBL arrangements is to increase readiness and availability while reducing overall sustainment costs in the long run” (Government Accountability Office, 2008).

The implementation of PBL has not been trouble free, and some ambiguity exists. The first significant finding of research conducted regarding PBL is that PBL is successful when implemented in a sub-system or component level rather than the entire system. The second finding is that the establishment of appropriate metrics linked to the required outcomes is fundamental for determining the level of PBL agreement effectiveness and whether it is better than the traditional approach. The third finding is that PBL is an approach that works and can give the desired results; inappropriate implementation is the reason for PBL shortcomings.

The most important metric that is in a warfighter’s center of interest is operational availability (Ao). Ao is easier to measure in the subsystem or component level. The warfighter and the decision maker can be assisted better if provided with the compound effect of all the subsystems or/and components. A tool for getting those compound effects is M&S. Such models can provide comprehensive results, having taken into account all the established metrics for each individual subsystem or component. M&S will provide the warfighter and the decision maker a basis for deciding on trade-offs between performance and cost. In addition, M&S can be utilized to evaluate various solution options. Finally, M&S can offer useful insight regarding logistic support during the whole acquisition cycle. A well-developed model can be proven to be a great tool for improvement or requirements modifications during the life of the system.

In the next chapter, the model developed for the LAV-25 study case is discussed. Case three is orientated in assisting decisions regarding PBL arrangements, either new ones or modifications.

V. LAV-25 CASE STUDY: DISCUSSION AND ANALYSIS

In this chapter, an initial Baseline Case will be used to calculate the Ao, readiness risk, and LCC for a Marine Expeditionary Force (MEF) with 76 LAV-25 vehicles and a life cycle of 20 years. The input data is based on failures rates (λ_i) for the five components (given in Table 1), a value range for the number of spares in the spare inventory, and maintenance turnaround times for an Op-Tempo that has a normal distribution with a mean of 500 and standard deviation of 60 hours per year (99.7% of the values are between a range of 300-700 hours)[14].

In the first part of the analysis, the authors assume that they cannot change the failure rates (λ_i) for the five critical components selected for the case study. The authors have procured the systems with the initial specifications on the failure rates, so they cannot change them. Also, they assume that they cannot change the mean Op-Tempo either. If the authors want to improve the components' failure rates (lower values), they will need a new acquisition contract. This will be the second part of the analysis, namely the cost benefit analysis between the two options of buying new improved components or improving the maintenance turnaround time (TAT).

Having the input and output results, the authors try to realize which of the input factors have the greater impact on Ao, readiness risk, and LCC. The authors will correlate all these data, present the results, and analyze the alternatives.

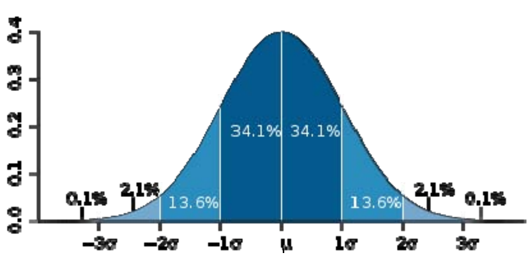
A. BASELINE CASE

For the Baseline Case, the authors use the input data as following (Table 5):

Input Parameter (factors)	Input Values (generate random values)
Failure rate for component i (λ_i, i = 1, 2, …, 5)	The reciprocal of the Poisson random variates generated with the mean displayed in column 4 of Table 6
Number of spares in the spare inventory for the component i (i = 1, 2, …, 5)	Normal distribution with mean (μ) =5 spares and standard deviation (σ)=1.5 spares $N(5, 1.5)$ (99.7% of the values are between a range 1-9 spares)[14]
3rd Echelon-TAT (3rd Echelon turnaround time)	Normal distribution $N(7.5, 2.5)$ in days, (99.7% of the values are between a range 1-15 days)
4th Echelon-TAT (4th Echelon turnaround time)	Normal distribution $N(60, 10)$ in days, (99.7% of the values are between a range 30-90 days)
Op-Tempo	Normal distribution $N(500, 60)$ in operational hours per year, (99.7% of the values are between a range 300-700 op. hours).

Table 5. Values of Input Parameters for Baseline Case

[14] Dark blue is less than one standard deviation (σ) from the mean (μ). For the normal distribution, this accounts for about 68% of the set (dark blue), while two standard deviations from the mean (medium and dark blue) account for about 95%, and three standard deviations (light, medium, and dark blue) account for about 99.7%



According to the data from Table 1, the data for the failure rate were provided as the number of failures per million days, which is too low. Even using one calendar day as a time unit, the failure rates still remain too low, or the components are unusually too reliable. Instead of the failures per million days in their project, the authors will use the provided data as failures per calendar hour. Since the failure rate still remains low, the authors will generate failures per operating hours, keeping the same proportionality between components' failures as the initial data (Table 6)

Component No	**Failures per calendar hour** (data from Table 1)	**Mean Time between Failures**	**Mean Time between Operating hours**	**Failure rate per op. hour** λ_i
1	0.00021	4725.05	196.88	0.0051
2	0.00036	2752.45	114.68	0.0087
3	0.00009	11227.84	467.83	0.0021
4	0.00011	9145.26	381.05	0.0026
5	0.00012	7875.08	328.13	0.0030

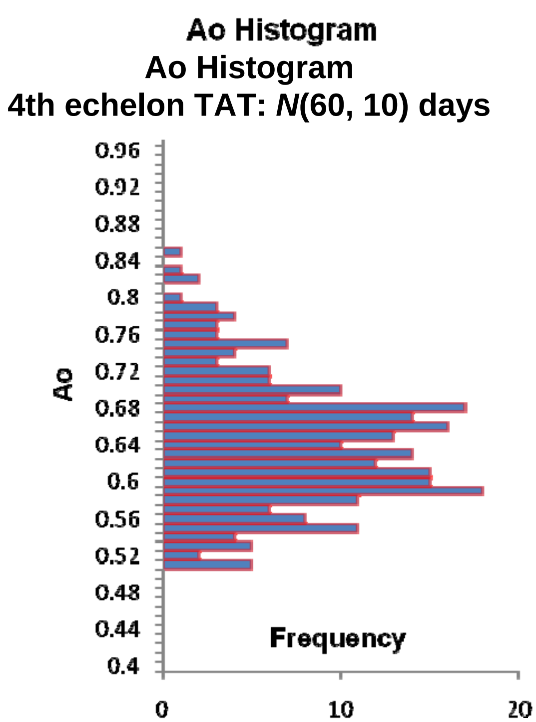
Table 6. Expected Frequency of Component Failure Rates

The Excel spreadsheet model uses as inputs the following data (Table 7):

Input Parameter for Excel Spreadsheet	**Input Values** (Any of these values can be modified by the user)
Number of weapon systems	76
Life cycle period	20 years
Hourly operating cost	$100
Hourly repair cost, including material cost	$300
Transportation cost per failure	$200
Annual discount rate	7%
Annual inventory rate	20%
Protection Level for Critical Components	0.95

Table 7. Input Values for the Excel Spreadsheet Model

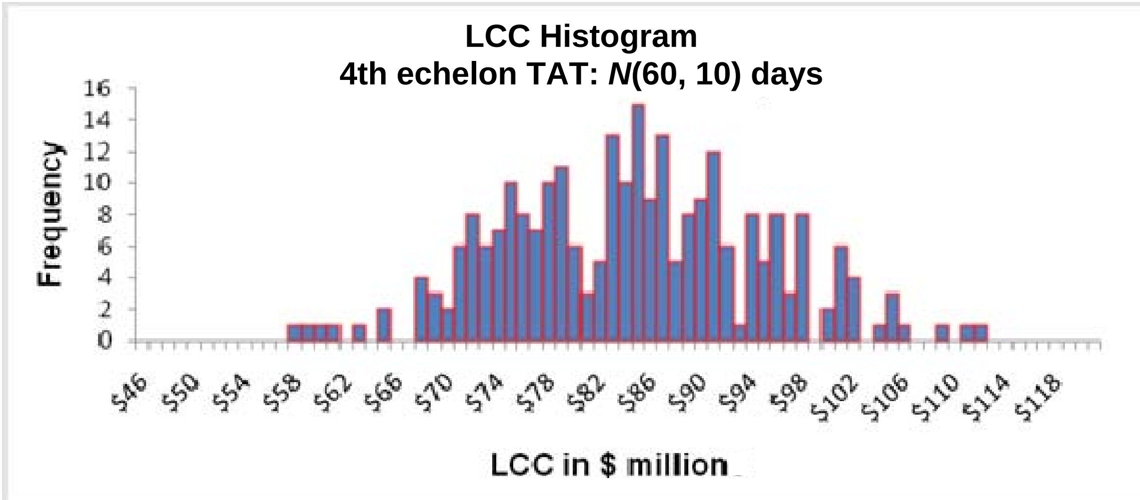
The results (Ao and LCC) from the Baseline Case scenarios are represented in histograms with their descriptive statistics in Figures 11 and 12.



Ao descriptive statistic Baseline Case (for 20 years)	
Mean	*0.63*
Standard Error	*0.004*
Median	*0.63*
Standard Deviation	*0.06*
Range	*0.34*
Minimum	*0.50*
Maximum	*0.84*
Scenarios Count	*257*

The mean Ao=0.63 with maximum Ao=0.84 and minimum Ao=0.5. The mean Ao is much lower than the target mean Ao of 0.85.

Figure 11. Ao Distribution and Descriptive Statistics for the Baseline Case



LCC in $ million (for 20 years)	
Mean	*84.04*
Standard Error	*0.63*
Median	*84.12*
Standard Deviation	*10.12*
Range	*54.41*
Minimum	*57.17*
Maximum	*111.58*
Scenarios Count	*257*

The mean LCC=$84.04 million with maximum LCC=$111.58 million and minimum LCC=$57.17 million.

Figure 12. LCC Distribution and Descriptive Statistics for the Baseline Case

Using the distribution of Ao values, the authors can extract the quantiles of Ao (in this case they will be 55%, 60%, 65%,..., 95%, 100% of Ao). The cumulative Ao is illustrated in Figure 13. The authors can note that the probability that the Ao falls below 0.55 is 10.51%. The probability that the Ao falls below 0.75 is 93% (the probability that the Ao is above 0.75 is only 17%). This is a high readiness risk at the threshold Ao of 75%, in accordance with the authors' target in Chapter III.

Ao	*Frequency (quantiles of Ao)*	*Cumulative Operational Availability*
0.50	0	0.00%
0.55	27	10.51%
0.60	58	33.07%
0.65	64	57.98%
0.70	64	82.88%
0.75	26	93.00%
0.80	14	98.44%
0.85	4	100.00%
0.90	0	100.00%

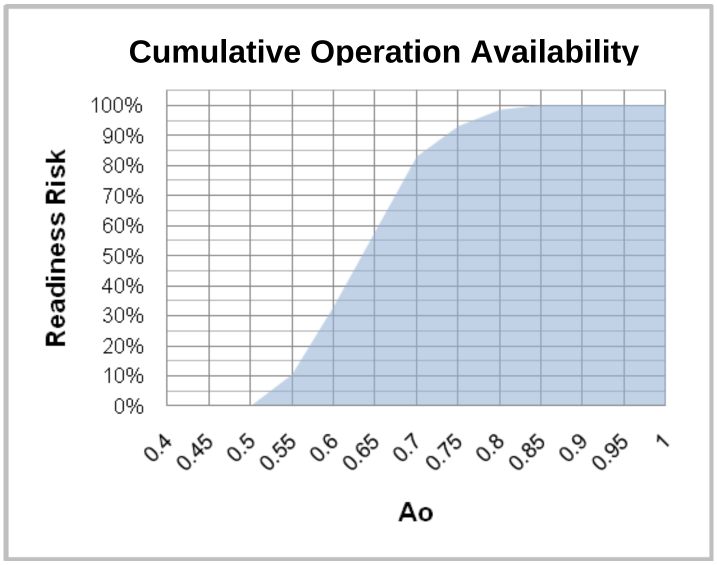


Figure 13. Ao's Quantiles and the Cumulative Operational Availability for the Baseline Case

Using the correlation data (Table 8) between the inputs and outputs value, the authors will analyze which of the input values have more influence on Ao and LCC. The factors that are most influential for Ao in order of precedence are the 4th echelon TAT (as the 4th echelon TAT increases, the Ao value decreases and vice versa), Op-Tempo, number of spares for component 1 (sensor unit, laser) in the spare pool, and the number of spares for component 5 (engine, diesel) in the spare pool. All other factors have a minor impact on Ao. The factors that are most influential for LCC in order of precedence are the Op-Tempo and failure rate of component 2 (control display unit).

In accordance with the above results, the authors will try to improve the Ao and reduce the readiness risk using another two cases. In Case One, the authors will reduce the 4^{th} echelon TAT to a mean of 45 days with a standard deviation of 4.5 days following the normal distribution (99.7% of the values are between 31.5 and 58.5 days). In Case Two, the authors will reduce the 4^{th} echelon TAT to a mean of 30 days with a standard deviation of 4.5 days following a normal distribution (99.7% of the values are between 16.5 and 43.5 days).

Input – Output Values Correlation

	Input Data derived from Table 6					N(5, 1.5) spares in the inventory					N(7.5, 2.5)	N(60, 10) days	N(500, 60) hours/year		
	λ_1	**λ_2**	**λ_3**	**λ_4**	**λ_5**	***spare 1***	***spare 2***	***spare 3***	***spare 4***	***spare 5***	***3rd echelonTAT***	***4th echelonTAT***	***Op tempo***	***Ao***	***LCC***
λ_1	1														
λ_2	-0.03376	1													
λ_3	-0.17552	0.001272	1												
λ_4	0.090261	-0.09214	0.09614	1											
λ_5	0.044352	-0.02036	-0.01274	0.066391	1										
spare 1	-0.05929	0.003439	0.01349	0.012255	-0.02088	1									
spare 2	0.01756	-0.05588	-0.00777	-0.03592	-0.05576	-0.04283	1								
spare 3	-0.10946	-0.09229	-0.00777	0.000616	-0.01766	-0.00789	0.066657	1							
spare 4	-0.03187	0.036631	0.058836	-0.01385	0.037114	0.045637	-0.00587	-0.02635	1						
spare 5	0.001369	0.04215	0.02098	-0.03192	-0.05403	-0.00529	0.149273	-0.0584	-0.0109	1					
3rd echelon	0.030175	-0.07747	0.033213	-0.00981	0.022414	0.083675	-0.05953	0.061468	0.072211	-0.16543	1				
4th echelon	0.049821	0.040262	-0.04692	-0.00501	-0.00865	-0.09263	0.012036	-0.11281	-0.04546	-0.07618	0.042226245	1			
Tempo	-0.06475	0.016705	0.016163	-0.03088	0.026733	-0.00923	-0.04535	-0.07125	0.026322	0.013286	-0.02273037	0.00549725	1		
Ao	-0.165	-0.04276	0.057197	-0.03824	-0.09614	0.27063	0.098817	0.116188	0.19149	0.230339	-0.06459197	-0.76712909	-0.520721	1	
LCC	0.011142	0.100795	0.051412	-0.00987	0.04835	0.020793	-0.04018	-0.08163	0.048151	0.028931	-0.02223527	0.004319335	0.99075815	-0.518516	1
Order of precedence for Ao influence	**6**					**3**		**7**	**5**	**4**		**1**	**2**		
Order of precedence for LCC influence		**3**											**1**	**2**	

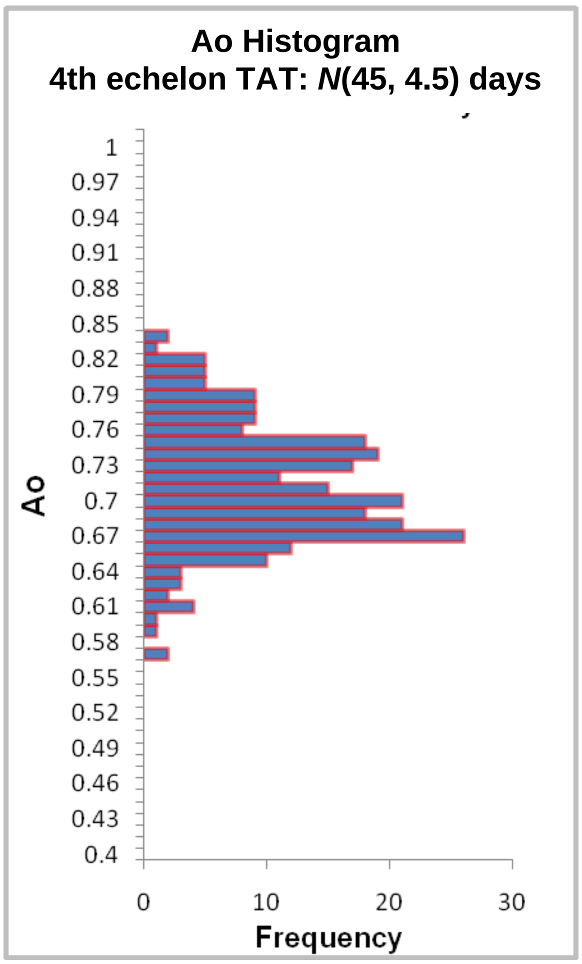
Table 8. Input–Output Values Correlation

B. PART ONE – CASE ONE (4TH ECHELON TAT *N*(45, 4.5))

For Case One, the authors use the input data from the Table 2, except 4th echelon TATs, which are:

4th Echelon-TAT for Case One	Normal distribution $N(45, 4.5)$ in days, (99.7% of the values are between a range 31.5-58.5 days)

The results (Ao, LCC, readiness risk and the cumulative operational availability) from the Case One scenarios are represented in histograms with their descriptive statistics in Figures 14 and 15).



Ao descriptive statistic Case One (for 20 years)	
Mean	*0.70*
Standard Error	*0.003*
Median	*0.70*
Standard Deviation	*0.05*
Range	*0.27*
Minimum	*0.56*
Maximum	*0.83*
Scenarios Count	*257*

The mean Ao=0.73 (better than the Basiline Case of Ao=0.63) with maximum Ao=0.83 and minimum Ao=0.56. The mean Ao has improved but still remains lower than the target value.

Figure 14. Ao Distribution and Descriptive Statistics for Case One

The LCC distribution does not significantly change as compared to the Baseline Case (the product of the average repair time multiplied by the hourly charge for repair including material cost does not significantly change).

Ao	*Frequency (quantiles of Ao)*	*Cumulative Operational Availability*
0.50	0	0.00%
0.55	0	0.00%
0.60	4	1.56%
0.65	22	10.12%
0.70	98	48.25%
0.75	80	79.38%
0.80	40	94.94%
0.85	13	100.00%
0.90	0	100.00%

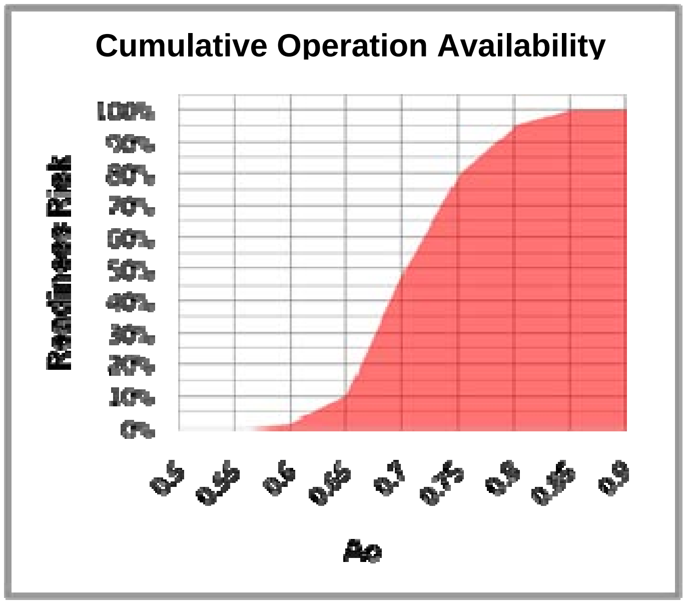


Figure 15. Ao's Quantiles and the Cumulative Operational Availability for Case One

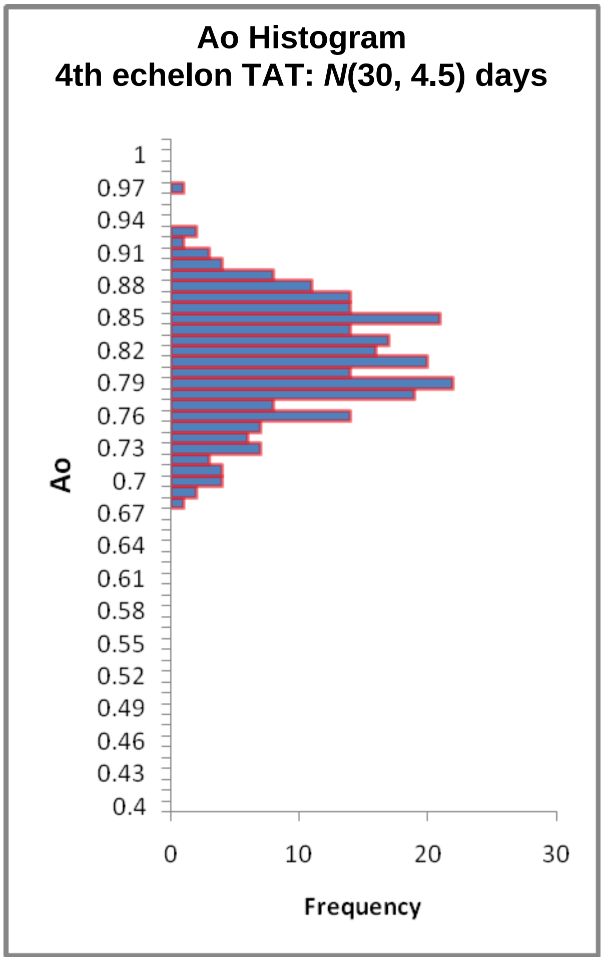
The probability that the Ao falls below 0.75 is 79.38% (the probability that the Ao is above 0.75 is only 20.62%), as seen in Figure 15. This still remains a high readiness risk for the threshold Ao of 75%, in accordance with the authors' target in Chapter III.

C. PART ONE – CASE TWO (4TH ECHELON TAT *N*(30, 4.5))

For Case Two, the authors use the input data from Table 2, except 4th echelon TATs, which are:

4th Echelon-TAT for Case Two	Normal distribution $N(30, 4.5)$ in days, (99.7% of the values are between a range 16.5-43.5 days)

The results (Ao, LCC, readiness risk and the cumulative operational availability) from the Case Two scenarios are represented in histograms with their descriptive statistics in Figures 16 and 17.



Ao descriptive statistic Case Two (for 20 years)	
Mean	*0.81*
Standard Error	*0.003*
Median	*0.81*
Standard Deviation	*0.05*
Range	*0.29*
Minimum	*0.67*
Maximum	*0.97*
Scenarios Count	*257*

The mean Ao=0.81 (better than the Baseline Case mean Ao=0.63, and Case One mean Ao=.73) with maximum Ao=0.97 and minimum Ao=0.67. The Ao has significantly improved and it is close to the target mean Ao of 0.85.

Figure 16. Ao Distribution and Descriptive Statistics for Case Two

Ao	Frequency (quantiles of Ao)	*Cumulative Operational Availability*
0.60	0	0.00%
0.65	0	0.00%
0.70	7	2.72%
0.75	27	13.23%
0.80	77	43.19%
0.85	88	77.43%
0.90	51	97.28%
0.95	6	99.61%
1.00	1	100.00%

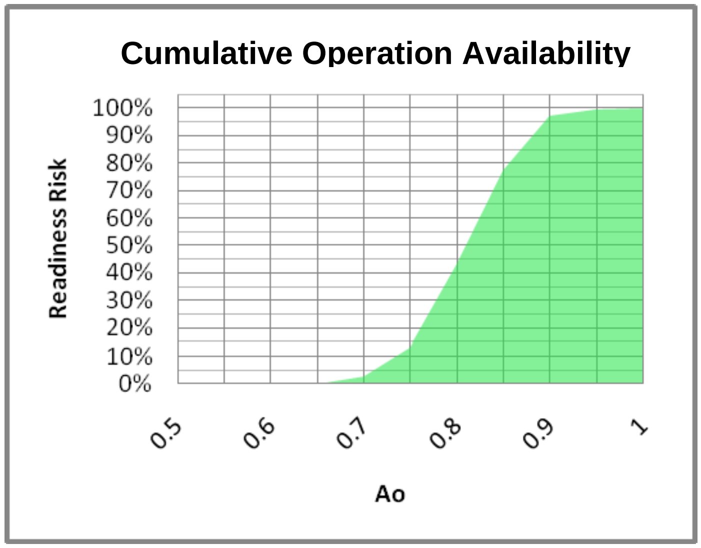


Figure 17. Ao's Quantiles and the Cumulative Operational Availability for Case Two

As can be seen in Figure 17, the probability that the Ao falls below 0.75 is 13.23%. There is improvement in readiness risk close to the threshold set for this report (Prob [Ao < 0.75] < 0.10).

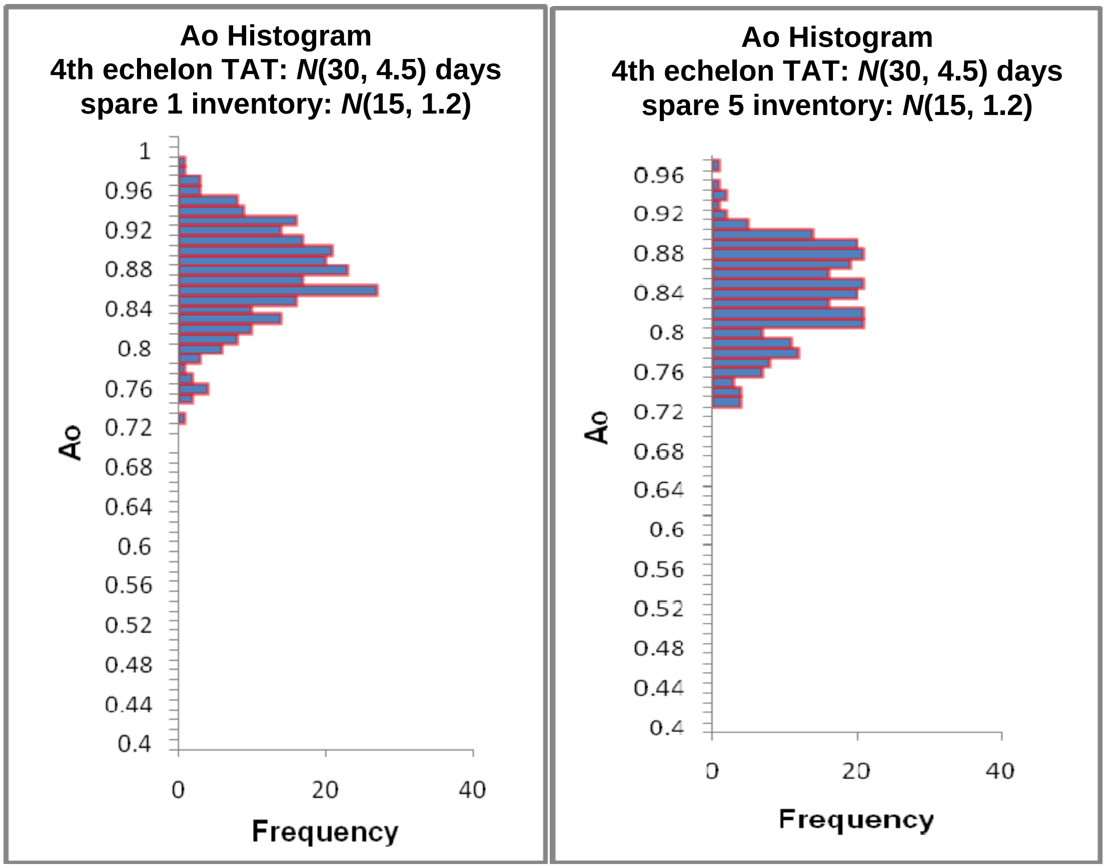
D. PART ONE – CASE THREE (INCREASE NUMBER OF SPARES IN THE SPARE INVENTORY: *N*(15, 1.2) SPARES FOR COMPONENT 1 OR COMPONENT 5)

Using the correlation data from the Baseline Case (Table 8) between the input and output values, the authors will try to further improve the Ao by changing the numbers of spares in the inventory from *N*(5, 1.5) to *N*(15, 1.2), for spares of component 1 and of component 5 alternatively (either spares for component 1 or spares for component 5 were changed, but not simultaneously). In accordance with the correlation table (Table 8), the number of spares in the inventory for components 1 and 5 are the factors with the 3rd and 4th highest impact on Ao. For Case Three, the authors will use the input data from Case Two (4th echelon TAT: *N*(30, 4.5)), except the number of spares in the spare inventory for component 1 and component 5 as they are shown below in Figure 18:

Input Parameter (factors)	**Input Values** (generate random values)
Failure rate for the component i (λ_i, i = 1, 2, …, 5)	The reciprocal of the Poisson random variates generated with the mean displayed in column 4 of Table 6
Number of spares in the spare inventory for the component i (i = 2, 3, 4)	Normal distribution with mean (μ) =5 spares and standard deviation (σ)=1.5 spares $\mathcal{N}(5, 1.5)$
Number of spares in the spare inventory first for the component 1 and then for the component 5 (separately)	Normal distribution with mean (μ) =15 spares and standard deviation (σ)=1.3 spares $\mathcal{N}(15,1.3)$ (99.7% of the values are between a range 10-20 spares)
3rd Echelon-TAT (3rd Echelon turnaround time)	Normal distribution $\mathcal{N}(7.5, 2.5)$ in days.
4th Echelon-TAT (4th Echelon turnaround time)	Normal distribution $\mathcal{N}(30, 4.5)$ in days
Op-Tempo	Normal distribution $\mathcal{N}(500, 60)$ in operational hours

Figure 18. Values of Input Parameters for Case Three

The results (Ao, readiness risk, cumulative operational availability and LCC) from the Case Three scenarios are represented in histograms with their descriptive statistics in Figures 19, 20, and 21.



Ao descriptive statistic (Spare 1 inventory: N(15, 1.2) spares)	
Mean	*0.87*
Standard Error	*0.003*
Median	*0.87*
Standard Deviation	*0.05*
Range	*0.26*
Minimum	*0.73*
Maximum	*0.99*
Scenarios Count	*257*

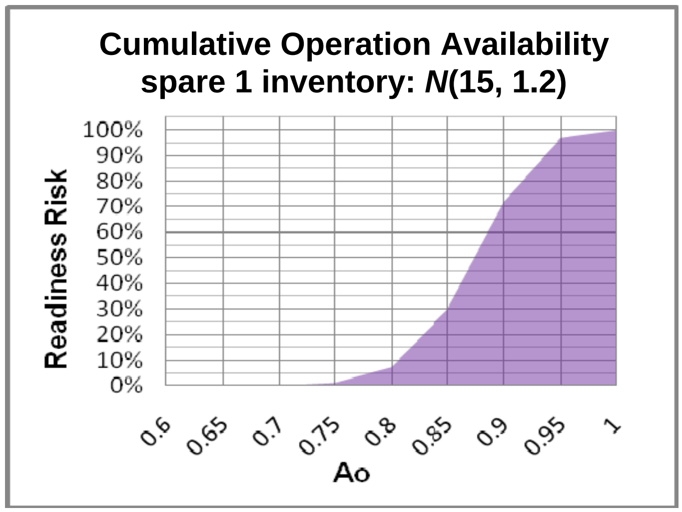
Ao descriptive statistic (Spare 5 inventory: N(15, 1.2) spares)	
Mean	*0.83*
Standard Error	*0.003*
Median	*0.84*
Standard Deviation	*0.05*
Range	*0.25*
Minimum	*0.72*
Maximum	*0.97*
Scenarios Count	*257*

Figure 19. Ao Distribution and Descriptive Statistics for Case Three (Increase Number of Spares: *N*(15, 1.2) in the Spare 1 and Spare 5 Inventories)

The authors can observe that the Ao distributions between the two sub-cases have a small difference (mean Ao=0.87 and 0.83 respectively), with a

small Ao advantage by increasing the spare inventory of component 1. For both sub-cases, the mean Ao=0.87 and 0.83 are better than the Baseline Case (mean Ao=0.63), Case One (mean Ao=.73), and Case Two (mean Ao=0.81) with maximum Ao=0.97-0.99 and minimum Ao=0.72-0.73. There is an aditional improvement in Ao by increasing the spare inventory. The better option for the Ao between the two inventories (spare 1 and 5) is to increase the spare 1 inventory (Figure 19).

Ao	*Frequency (quantiles of Ao)*	*Cumulative Operational Availability*
0.60	0	0.00%
0.65	0	0.00%
0.70	0	0.00%
0.75	3	1.17%
0.80	16	7.39%
0.85	58	29.96%
0.90	108	71.98%
0.95	64	96.89%
1.00	8	100.00%



Ao	*Frequency (quantiles of Ao)*	*Cumulative Operational Availability*
0.70	0	0.00%
0.75	11	4.28%
0.80	45	21.79%
0.85	99	60.31%
0.90	90	95.33%
0.95	11	99.61%
1.00	1	100.00%

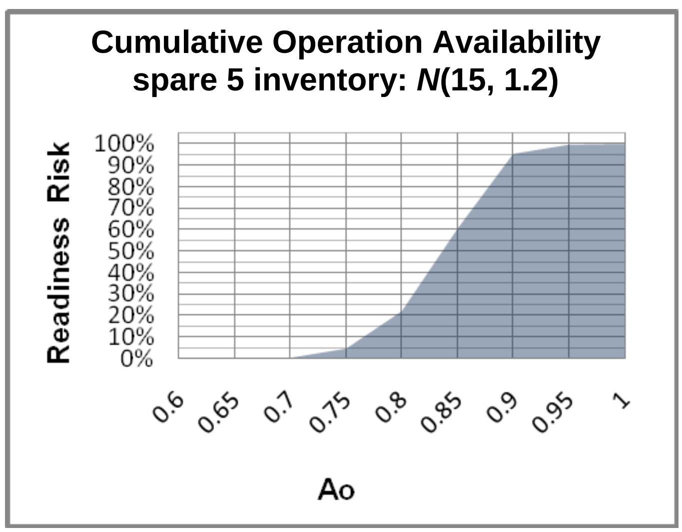
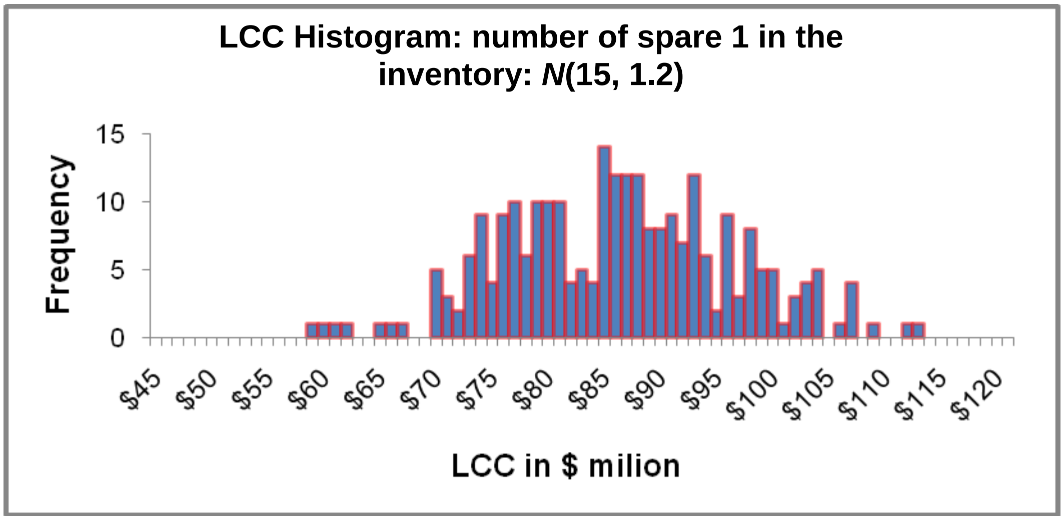


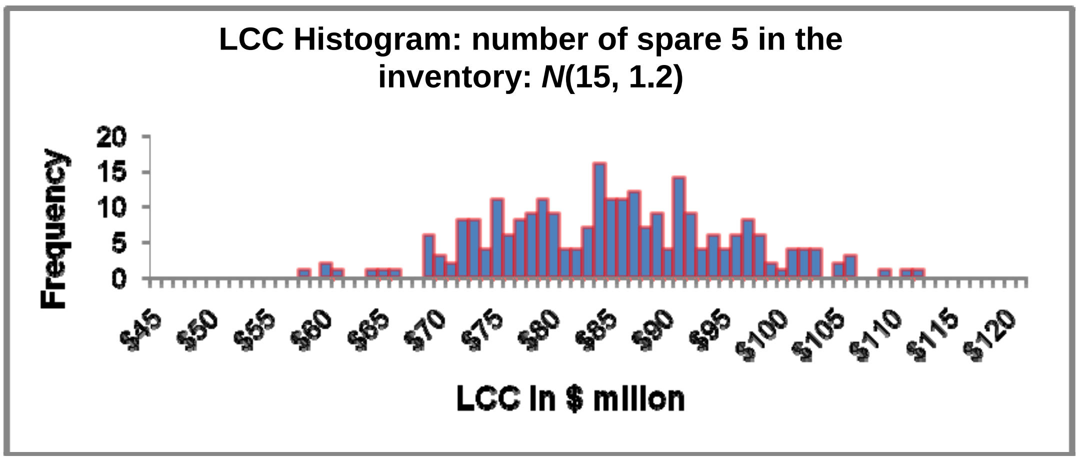
Figure 20. Ao's Quantiles and the Cumulative Operational Availability for Case Three

The probability that the Ao falls below 0.75 is only 1.17% and 4.28%, respectively. There is a significant improvement of readiness risk when the authors increase the spare 1 inventory number (Figure 20). From the above analysis, the authors would prefer to increase the spare 1 inventory instead of the spare 5 inventory, because it gives a higher mean Ao and a lower readiness risk.

As can be seen in Figure 21, the mean LCC is slightly increased (mean LCC=$85.83 million and $84.59 million, respectively, for the two sub-cases) in comparison with Cases One and Two (mean LCC=$84.04 million for Case One and Two).

The authors can achieve an increase in mean Ao by 6% (from 0.81 to 0.87) and at the same time decrease the readiness risk (probability that the mean Ao falls below 0.75) from 13.23% to less than 5% with a small additional cost (less than 2% increase in mean LCC).





LCC in $ million (Spare 1 inventory:N(15, 1.2) spares)		*LCC in $ million (Spare 5 inventory:N(15, 1.2) spares)*	
Mean	*85.83*	*Mean*	*84.59*
Standard Error	*0.63*	*Standard Error*	*0.63*
Median	*85.79*	*Median*	*84.66*
Standard Deviation	*10.14*	*Standard Deviation*	*10.13*
Range	*54.41*	*Range*	*54.53*
Minimum	*58.51*	*Minimum*	*57.34*
Maximum	*112.92*	*Maximum*	*111.87*
Scenarios Count	*257*	*Scenarios Count*	*257*

Figure 21. LCC Distribution and Descriptive Statistics for Case Three (Increase Number of Spares: *N*(15, 1.2) in the Spare 1 or Spare 5 Inventory)

E. ASSESSMENT FOR PART ONE (CASES ONE THROUGH THREE): IMPROVE TAT VERSUS INCREASE THE NUMBER OF SPARES IN INVENTORY

In comparing the results from Figures 22 and 23, the most significant factor in Ao improvement is the reduction in TAT. From the readiness risk assessment in Table 9 and the comparison chart (Figure 24), it is obvious that there is an incremental improvement in readiness risk. The most influential factor, as in Ao improvement, is the TAT. By Increasing only the number of spares in the spare inventory, there is almost no change in readiness risk (the detailed data and output results from this case are not shown here). A combination of a reduced TAT with an increase in the number of spares in the spare inventory further improves results for the readiness risk (Case Three).

The LCC distribution remains almost the same for Cases One, Two, and Three (Figure 25). It is slightly increased in Case Three in comparison with the Baseline Case, as well as Cases One and Two. The authors can achieve (case three) an increase in mean Ao by 6% and at the same time a decrease in the readiness risk (probability that the mean Ao falls below 0.75), from 13.23% to less than 5%, with a small additional cost.

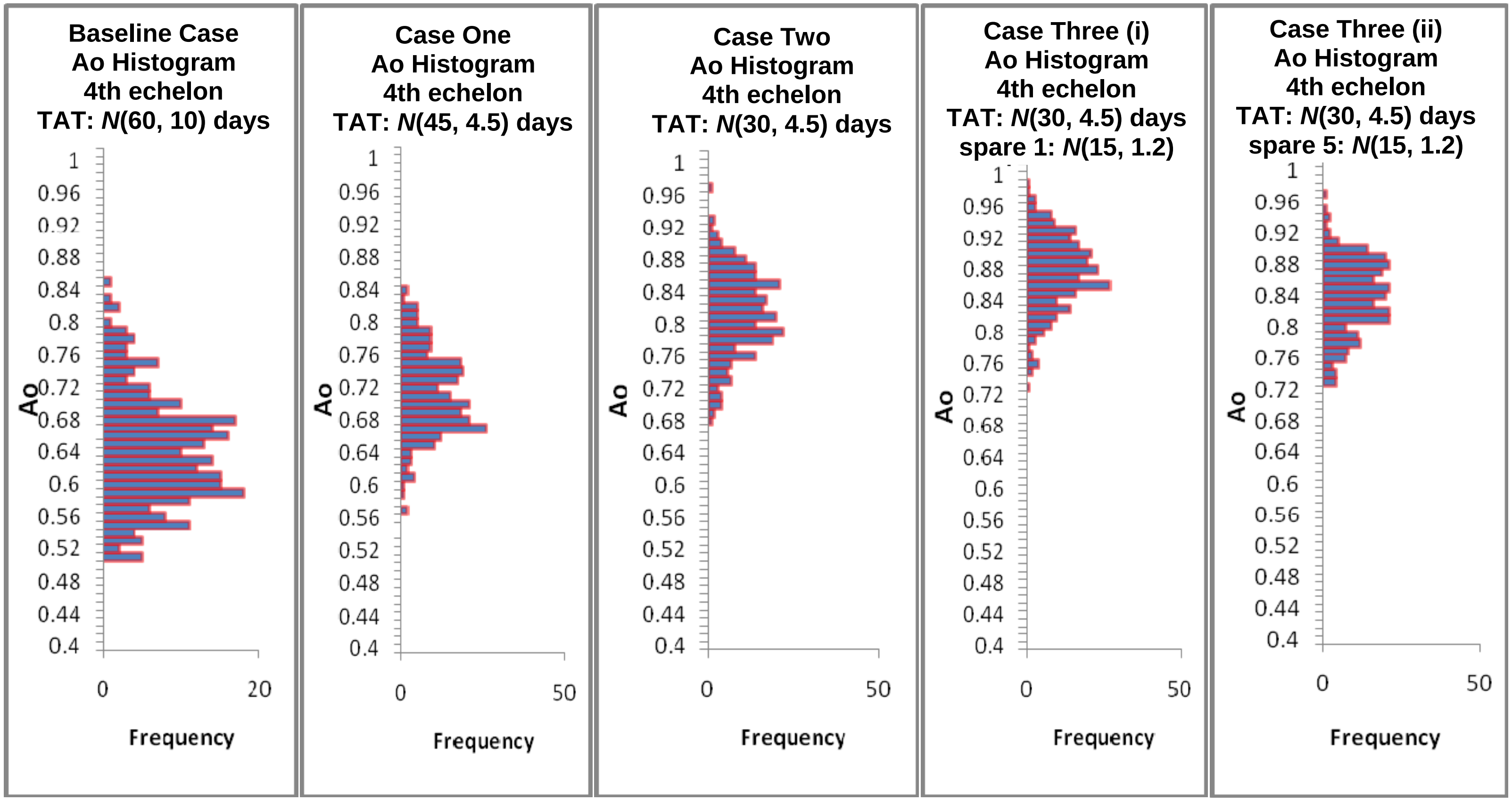


Figure 22. Ao Distribution Case Comparison for Part One

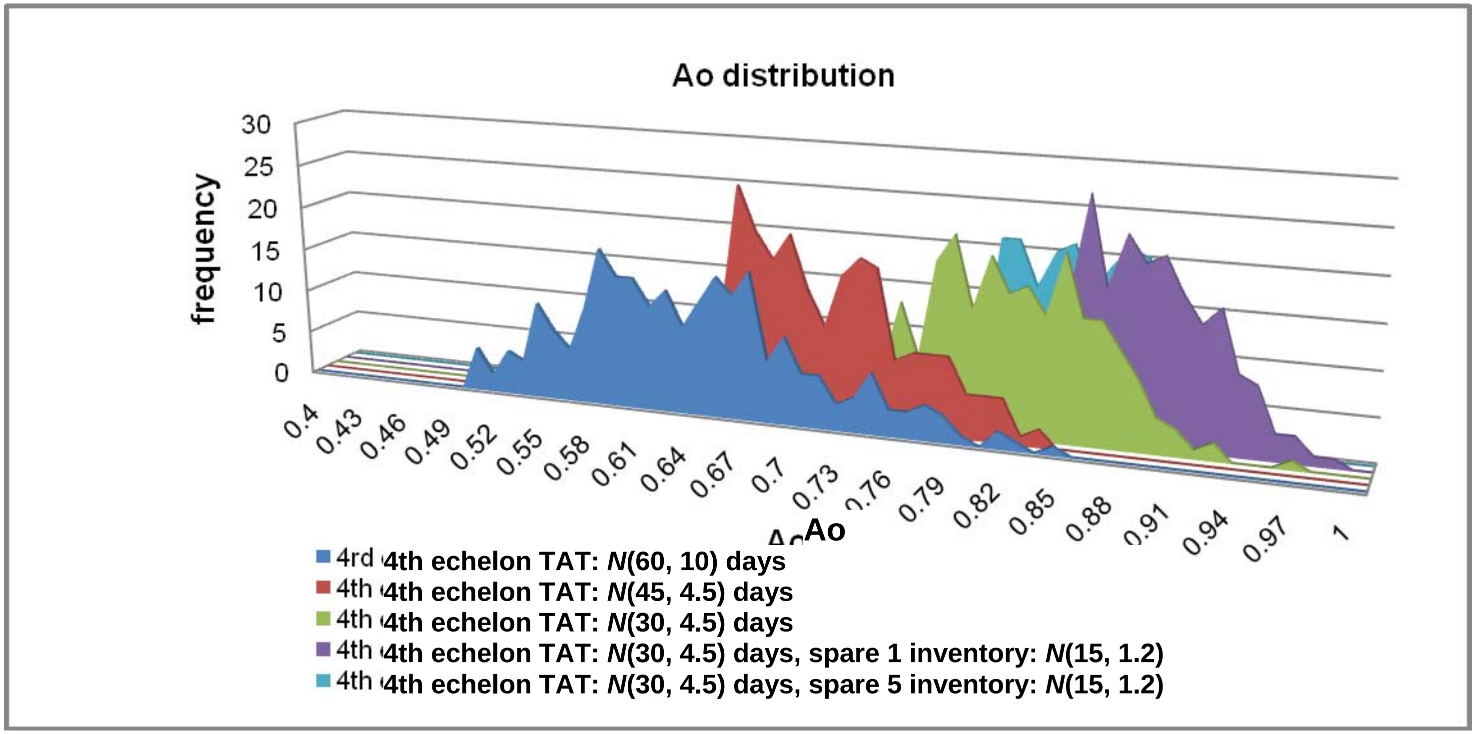


Figure 23. Ao Distribution Chart – Case Comparison for Part One

Readiness Risk Table										
	Baseline Case 4th echelon TAT: *N*(60, 10) days		Case One 4th echelon TAT: *N*(45, 4.5) days		Case Two 4th echelon TAT: *N*(30, 4.5) days		Case Three (i) TAT: *N*(30, 4.5) days spare 1 inventory: *N*(15, 1.2) spares		Case Three (ii) TAT: *N*(30, 4.5) days spare 5 inventory: *N*(15, 1.2) spares	
Ao	*Freq.*	*Cum. Ao*	*Freq.*	*Cum. Ao*	*Freq.*	*Cum. Ao*	*Freq.*	*Cum. Ao*	*Freq.*	*Cum. Ao*
0.50	0	0.00%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.51	5	1.95%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.52	2	2.72%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.53	5	4.67%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.54	4	6.23%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.55	11	10.51%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.56	8	13.62%	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.57	6	15.95%	2	0.78%	0	0.00%	0	0.00%	0	0.00%
0.58	11	20.23%	0	0.78%	0	0.00%	0	0.00%	0	0.00%
0.59	18	27.24%	1	1.17%	0	0.00%	0	0.00%	0	0.00%
0.60	15	33.07%	1	1.56%	0	0.00%	0	0.00%	0	0.00%
0.61	15	38.91%	4	3.11%	0	0.00%	0	0.00%	0	0.00%
0.62	12	43.58%	2	3.89%	0	0.00%	0	0.00%	0	0.00%
0.63	14	49.03%	3	5.06%	0	0.00%	0	0.00%	0	0.00%
0.64	10	52.92%	3	6.23%	0	0.00%	0	0.00%	0	0.00%
0.65	13	57.98%	10	10.12%	0	0.00%	0	0.00%	0	0.00%
0.66	16	64.20%	12	14.79%	0	0.00%	0	0.00%	0	0.00%
0.67	14	69.65%	26	24.90%	0	0.00%	0	0.00%	0	0.00%
0.68	17	76.26%	21	33.07%	1	0.39%	0	0.00%	0	0.00%
0.69	7	78.99%	18	40.08%	2	1.17%	0	0.00%	0	0.00%
0.70	10	82.88%	21	48.25%	4	2.72%	0	0.00%	0	0.00%
0.71	6	85.21%	15	54.09%	4	4.28%	0	0.00%	0	0.00%
0.72	6	87.55%	11	58.37%	3	5.45%	0	0.00%	0	0.00%
0.73	3	88.72%	17	64.98%	7	8.17%	1	0.39%	4	1.56%
0.74	4	90.27%	19	72.37%	6	10.51%	0	0.39%	4	3.11%
0.75	7	93.00%	18	79.38%	7	13.23%	2	1.17%	3	4.28%
0.76	3	94.16%	8	82.49%	14	18.68%	4	2.72%	7	7.00%
0.77	3	95.33%	9	85.99%	8	21.79%	2	3.50%	8	10.12%
0.78	4	96.89%	9	89.49%	19	29.18%	1	3.89%	12	14.79%
0.79	3	98.05%	9	93.00%	22	37.74%	3	5.06%	11	19.07%
0.80	1	98.44%	5	94.94%	14	43.19%	6	7.39%	7	21.79%
0.81	0	98.44%	5	96.89%	20	50.97%	8	10.51%	21	29.96%
0.82	2	99.22%	5	98.83%	16	57.20%	10	14.40%	21	38.13%
0.83	1	99.61%	1	99.22%	17	63.81%	14	19.84%	16	44.36%
0.84	0	99.61%	2	100.00%	14	69.26%	10	23.74%	20	52.14%
0.85	1	100.00%	0	100.00%	21	77.43%	16	29.96%	21	60.31%
0.86	0	100.00%	0	100.00%	14	82.88%	27	40.47%	16	66.54%
0.87	0	100.00%	0	100.00%	14	88.33%	17	47.08%	19	73.93%
0.88	0	100.00%	0	100.00%	11	92.61%	23	56.03%	21	82.10%
0.89	0	100.00%	0	100.00%	8	95.72%	20	63.81%	20	89.88%
0.90	0	100.00%	0	100.00%	4	97.28%	21	71.98%	14	95.33%
0.91	0	100.00%	0	100.00%	3	98.44%	17	78.60%	5	97.28%
0.92	0	100.00%	0	100.00%	1	98.83%	14	84.05%	2	98.05%
0.93	0	100.00%	0	100.00%	2	99.61%	16	90.27%	1	98.44%
0.94	0	100.00%	0	100.00%	0	99.61%	9	93.77%	2	99.22%
0.95	0	100.00%	0	100.00%	0	99.61%	8	96.89%	1	99.61%
0.96	0	100.00%	0	100.00%	0	99.61%	3	98.05%	0	99.61%
0.97	0	100.00%	0	100.00%	1	100.00%	3	99.22%	1	100.00%
0.98	0	100.00%	0	100.00%	0	100.00%	1	99.61%	0	100.00%
0.99	0	100.00%	0	100.00%	0	100.00%	1	100.00%	0	100.00%
1.00	0	100.00%	0	100.00%	0	100.00%	0	100.00%	0	100.00%

Table 9. Readiness Risk Assessment Table for Part One

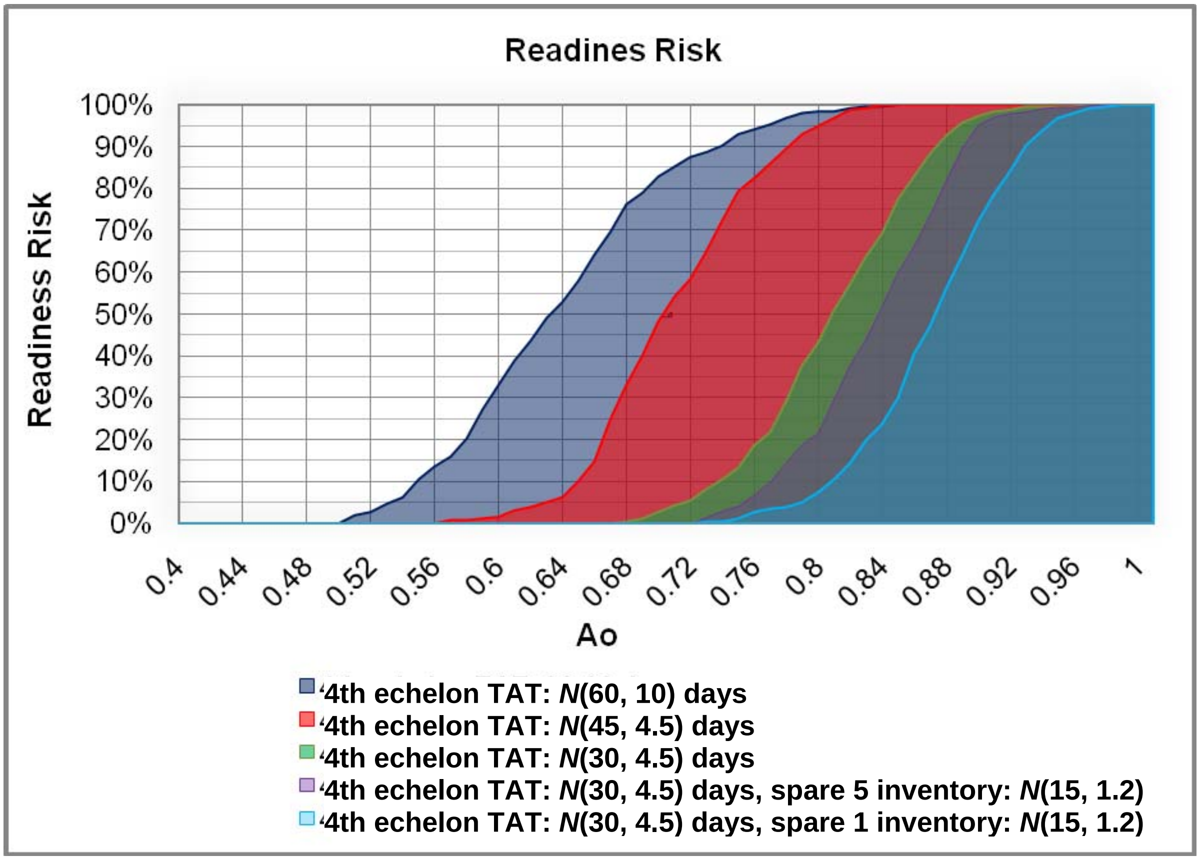


Figure 24. Readiness Risk Chart - Case Comparison for Part One

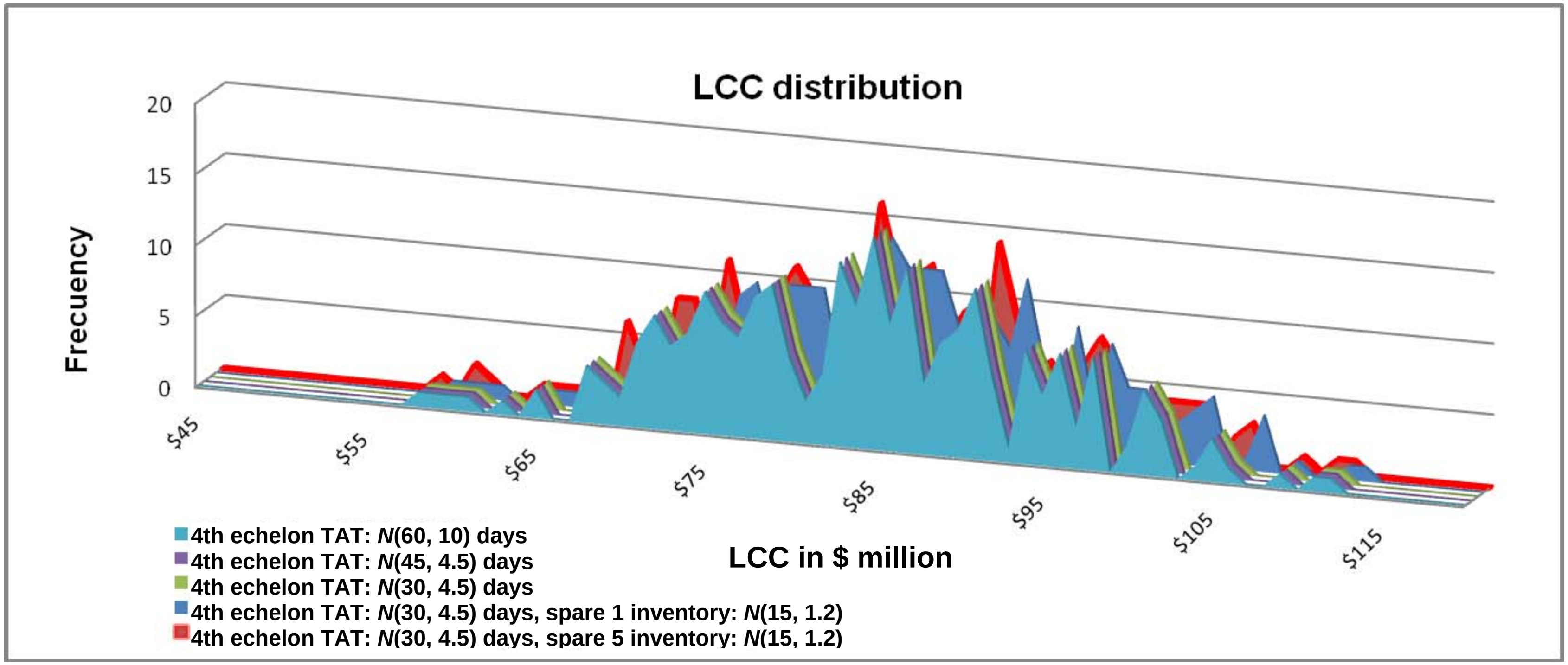


Figure 25. LCC Distribution Chart – Case Comparison for Part One

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F. PART TWO – CASE FOUR (DEMAND IMPROVED FAILURE RATE FOR COMPONENT 1 OR FOR ALL THE FIVE COMPONENTS)

Case Four uses the same input data as the Baseline Case (Table 5), except for the failure rates. Three distinct sub-cases are created. In sub-cases (i) and (ii), the mean failure rate of component 1 (sensor unit, laser) are improved from $\lambda=0.005$ to $\lambda=0.0033$ and $\lambda=0.0025$, respectively. In sub-case (iii), the failure rates of all five components are changed to $\lambda=0.0025$.

The results (Ao, readiness risk, cumulative operational availability, and LCC) from the Case Four sub-cases are displayed in the histograms with their descriptive statistics in Figures 26, 27, 28, and 29.

	Baseline Case	***Case Four (i)***	***Case Four (ii)***	***Case Four (iii)***
Mean	*0.64*	*0.69*	*0.72*	*0.75*
Standard Error	*0.0044*	*0.0043*	*0.0042*	*0.0043*
Median	*0.63*	*0.69*	*0.71*	*0.74*
Standard Deviation	*0.070*	*0.069*	*0.067*	*0.068*
Range	*0.35*	*0.34*	*0.32*	*0.34*
Minimum	*0.50*	*0.54*	*0.57*	*0.60*
Maximum	*0.85*	*0.88*	*0.89*	*0.94*
Scenarios Count	*257*	*257*	*257*	*257*

Figure 26. Ao Descriptive Statistics for Case Four Sub-cases

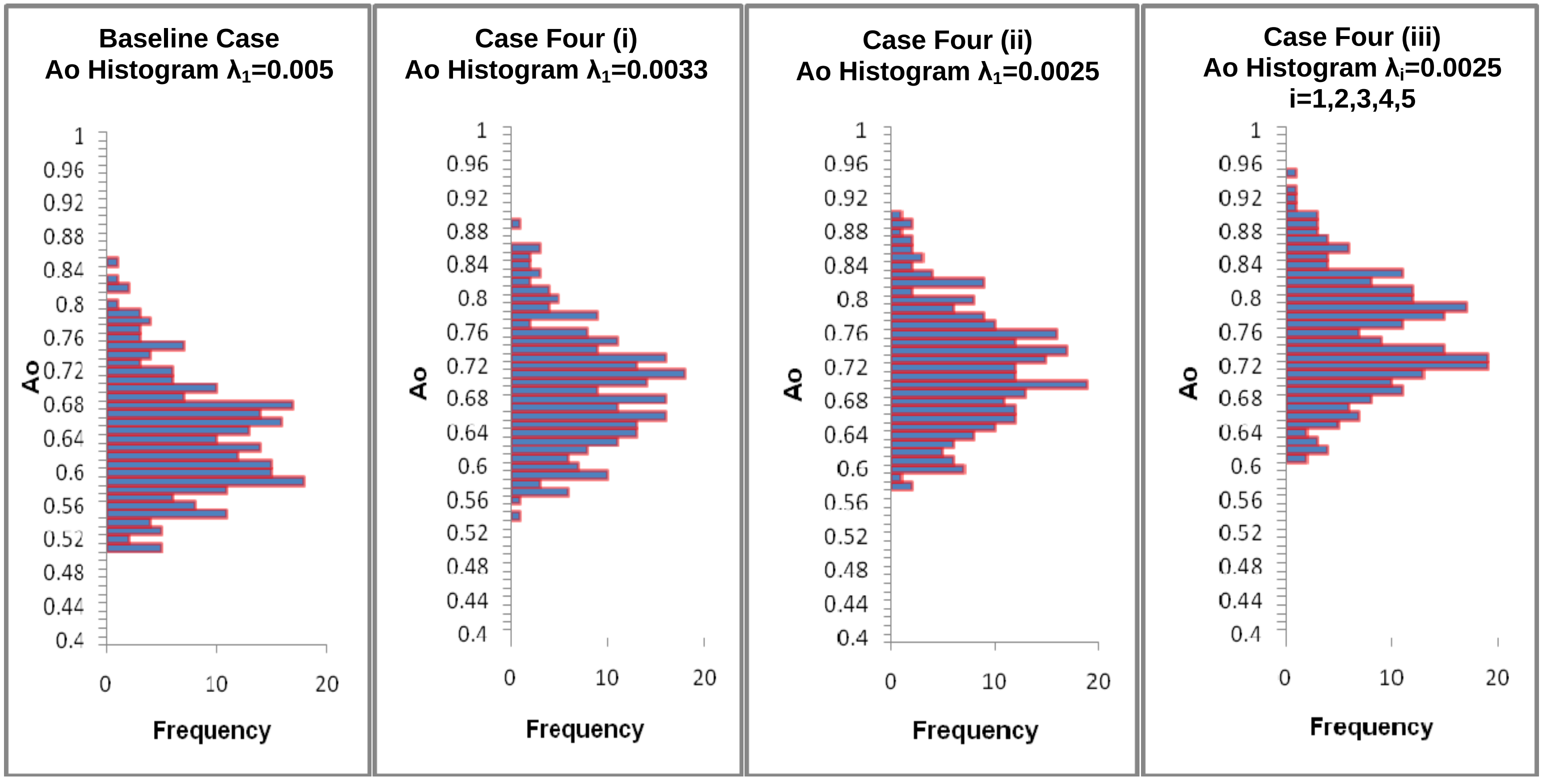
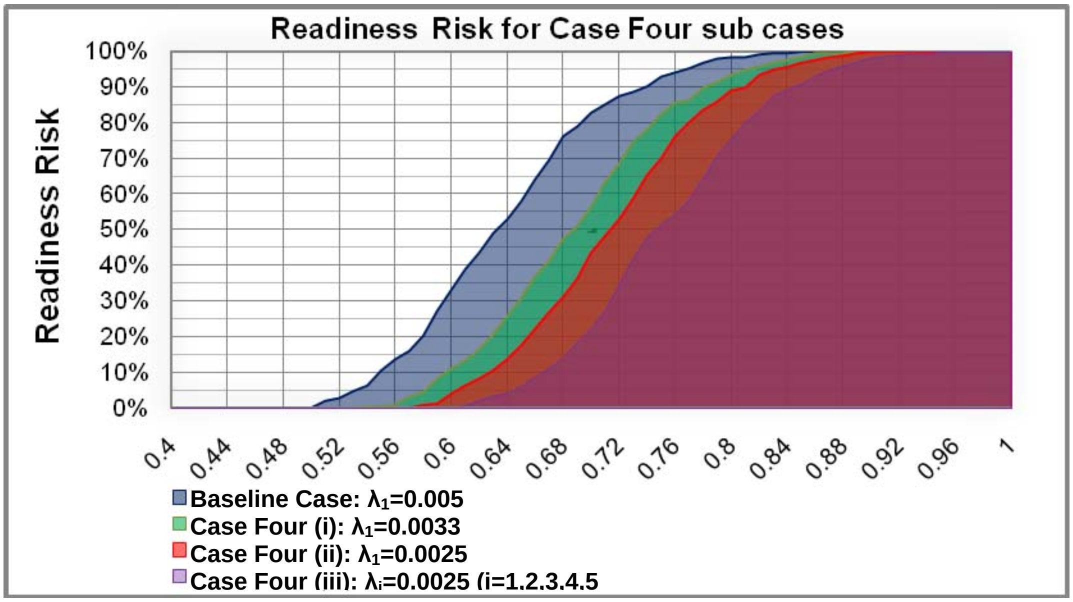


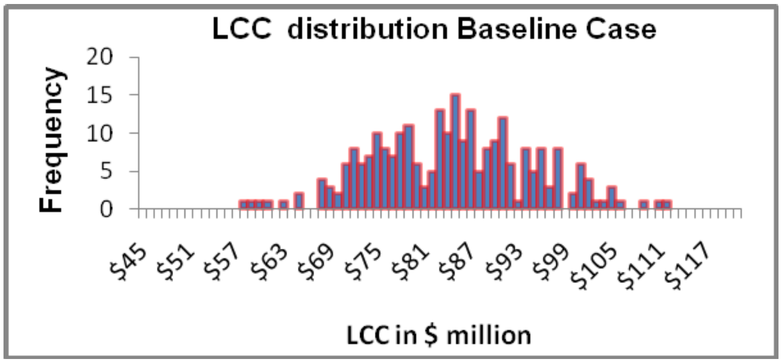
Figure 27. Ao Distribution Charts for Case Four Sub-cases

For all these sub-cases, there is improvement (Figure 27) for mean Ao (mean Ao=0.69, 0.72, and 0.75, respectively) in comparison with the Baseline Case (mean Ao value of 0.63), but the readiness risk still remains below the threshold Ao of 75% (Figure 28).

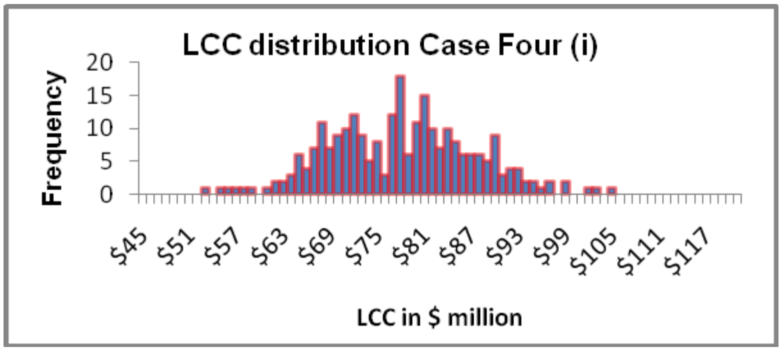


	Dase Line Case		*Case Four (i)*		*Case Four (ii)*		*Case Four (iii)*	
Ao	*Frequency (quantiles of Ao)*	*Cumulative operational availability*	*Frequency (quantiles of Ao)*	*Cumulative operational availability*	*Frequency (quantiles of Ao)*	*Cumulative operational availability*	*Frequency (quantiles of Ao)*	*Cumulative operational availability*
0.40	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.45	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.50	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.55	27	10.51%	1	0.39%	0	0.00%	0	0.00%
0.60	58	33.07%	27	10.89%	10	3.89%	0	0.00%
0.65	64	57.98%	51	30.74%	35	17.51%	16	6.23%
0.70	64	82.88%	66	56.42%	67	43.58%	42	22.57%
0.75	26	93.00%	67	82.49%	68	70.04%	75	51.75%
0.80	14	98.44%	28	93.39%	49	89.11%	62	75.88%
0.85	4	100.00%	13	98.44%	20	96.89%	39	91.05%
0.90	0	100.00%	4	100.00%	8	100.00%	19	98.44%
0.95	0	100.00%	0	100.00%	0	100.00%	4	100.00%
1.00	0	100.00%	0	100.00%	0	100.00%	0	100.00%

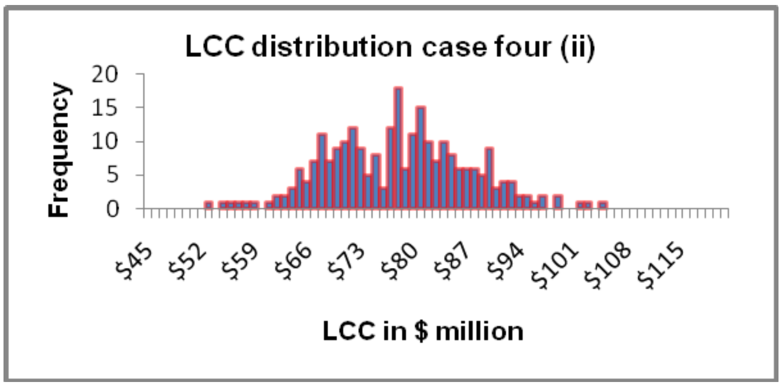
Figure 28. Readiness Risk for Case Four Sub-cases



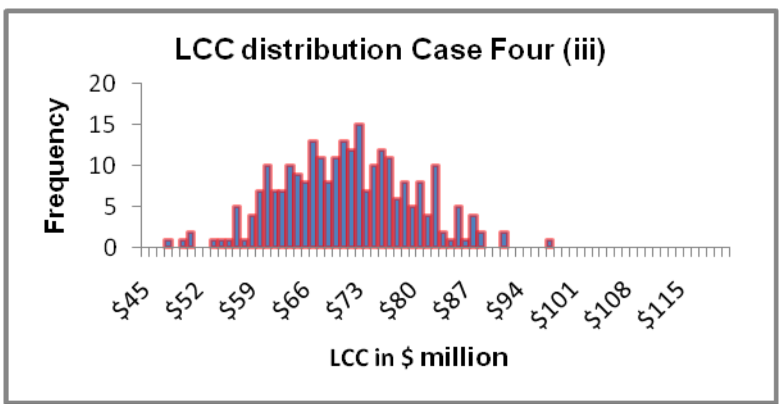
Baseline Case (in $ million)	
Mean	84.05
Standard Error	0.63
Median	84.12
Standard Deviation	10.12
Range	54.41
Minimum	57.17
Maximum	111.59
Scenarios Count	257



Case Four (i) (in $ million)	
Mean	79.70
Standard Error	0.60
Median	79.69
Standard Deviation	9.61
Range	51.79
Minimum	54.15
Maximum	105.94
Scenarios Count	257



Case Four (ii) (in $ million)	
Mean	77.63
Standard Error	0.59
Median	77.62
Standard Deviation	9.40
Range	51.70
Minimum	52.62
Maximum	104.33
Scenarios Count	257



Case Four (iii) (in $ million)	
Mean	70.87
Standard Error	0.53
Median	70.60
Standard Deviation	8.56
Range	50.36
Minimum	47.18
Maximum	97.54
Scenarios Count	257

Figure 29. LCC Distribution and Descriptive Statistics for Case Four Sub-cases

The LCC is incrementally reduced (Figure 29) from the Baseline Case and sub-case one through sub-case three (mean LCC in millions: 84.05, 79.7, 77.63, and 70.87 respectively).

G. PART TWO – CASE FIVE (LOWER FAILURE RATE FOR CRITICAL COMPONENTS IN COMBINATION WITH CASE THREE)

Case Five is a combination of Cases Three and Four. Three sub-cases are created. The input factor of 4th echelon TAT is set as in Case Three $N(30, 4.5)$ days with $N(15, 1.2)$ spares for component 1 in the spare inventory. Each sub-case uses the failure rates of the respective sub-cases, as in Case Four. The failure rate of component 1 is improved from $\lambda=0.005$ to $\lambda=0.0033$ and $\lambda=0.0025$, respectively. In sub-case (iii), the failure rates of all five components are changed to $\lambda=0.0025$.

The results (Ao, readiness risk, cumulative operational availability, and LCC) from the Case Five sub-cases are represented in histograms with their descriptive statistics in Figures 30, 31, 32, 33, and 34.

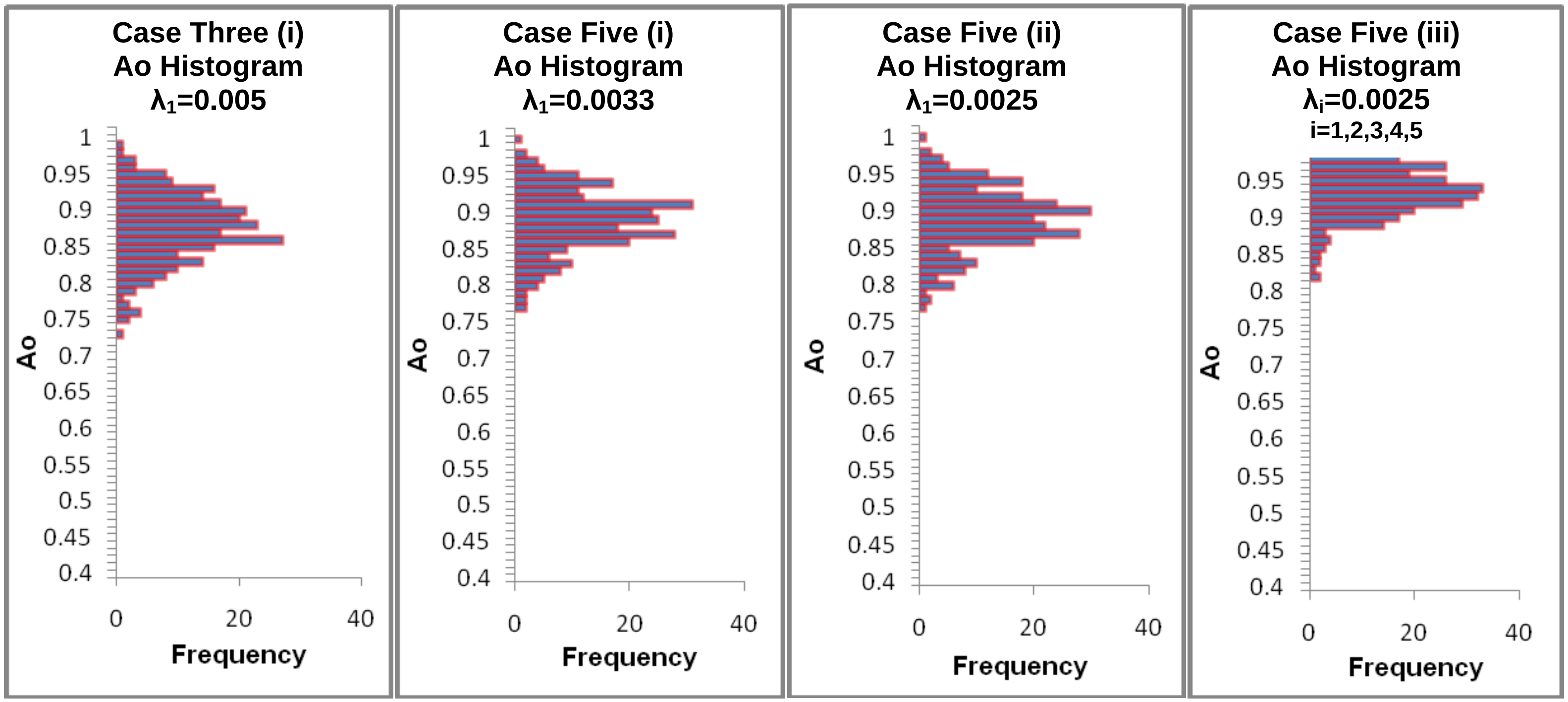


Figure 30. Ao Distribution Charts for Case Five Sub-cases

	Case Three (i)	*Case Five (i)*	*Case Five (ii)*	*Case Five (iii)*
Mean	*0.87*	*0.88*	*0.88*	*0.93*
Standard Error	*0.0030*	*0.0027*	*0.0026*	*0.0021*
Median	*0.87*	*0.88*	*0.89*	*0.93*
Standard Deviation	*0.048*	*0.043*	*0.042*	*0.033*
Range	*0.26*	*0.23*	*0.22*	*0.18*
Minimum	*0.73*	*0.76*	*0.77*	*0.81*
Maximum	*0.99*	*0.99*	*0.99*	*0.99*
Scenarios Count	*257*	*257*	*257*	*257*

Figure 31. Ao Descriptive Statistics for Case Five Sub-cases

For sub-cases (i) and (ii), there is slight improvement for mean Ao (mean Ao=0.88) in comparison with the Case Three sub-case (i) (mean Ao was 0.87). For the sub-case (iii), there is even further improvement, with mean Ao=0.93. The improvement in sub-case (iii) is significantly above the target mean Ao of 0.85.

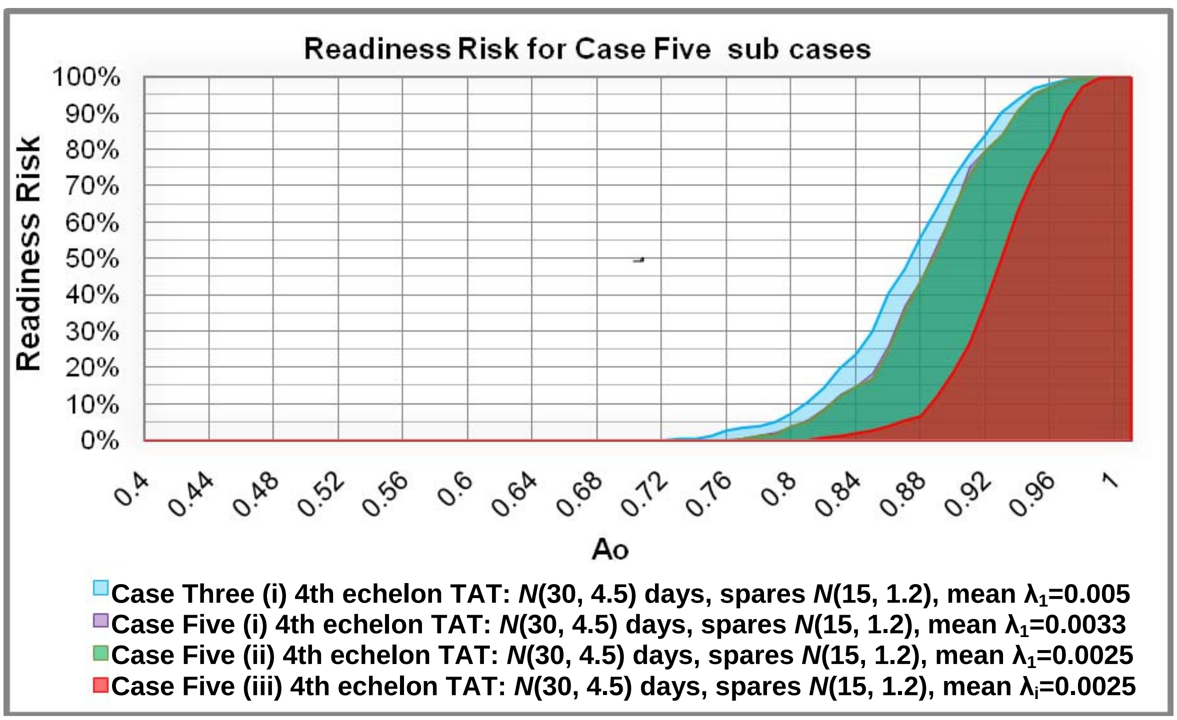


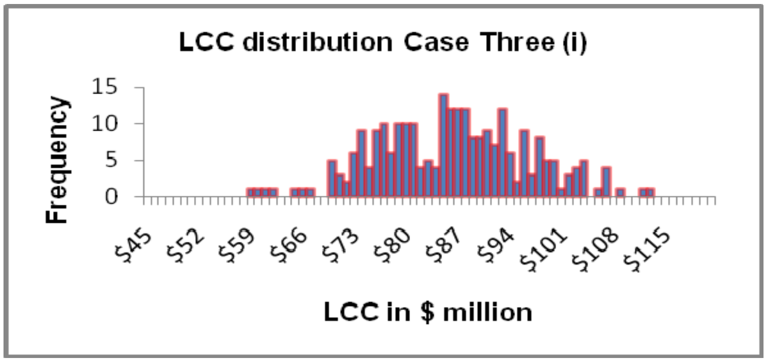
Figure 32. Readiness Risk Chart for Case Five Sub-cases

	Case Three (i)		Case Four (i)		Case Four (ii)		Case Four (iii)	
Ao	*Frequency (quantiles of Ao)*	*Cumulative operational availability*	*Frequency (quantiles of Ao)*	*Cumulative operational availability*	*Frequency (quantiles of Ao)*	*Cumulative operational availability*	*Frequency (quantiles of Ao)*	*Cumulative operational availability*
0.40	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.45	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.50	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.55	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.60	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.65	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.70	0	0.00%	0	0.00%	0	0.00%	0	0.00%
0.75	3	1.17%	0	0.00%	0	0.00%	0	0.00%
0.80	16	7.39%	10	3.89%	10	3.89%	0	0.00%
0.85	58	29.96%	38	18.68%	33	16.73%	7	2.72%
0.90	108	71.98%	115	63.42%	120	63.42%	41	18.68%
0.95	64	96.89%	82	95.33%	82	95.33%	140	73.15%
1.00	0	100.00%	0	100.00%	0	100.00%	0	100.00%

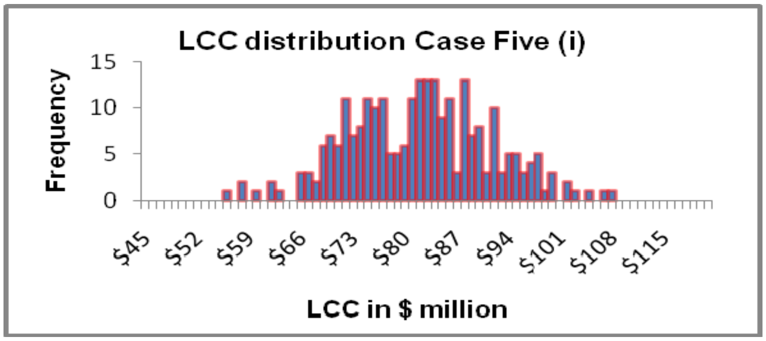
Figure 33. Readiness Risk for Case Five Sub-cases

For all Case Five sub-cases, there is improvement to the readiness risk (the probability that Ao falls below 0.75 is 0%), with the better one in sub-case (iii) (the probability that Ao falls below 0.85 is only 2.72%).

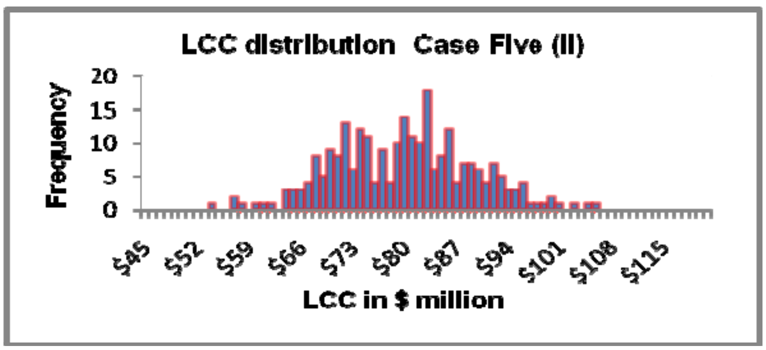
The LCC is incrementally reduced (Figure 34) from Case Three (i) to Case Five sub-cases (i), (ii) and (iii) (mean LCC is progressively reduced from $85.83 million to $72.64 million, a reduction of 15% compared to Case Three (i) LCC).



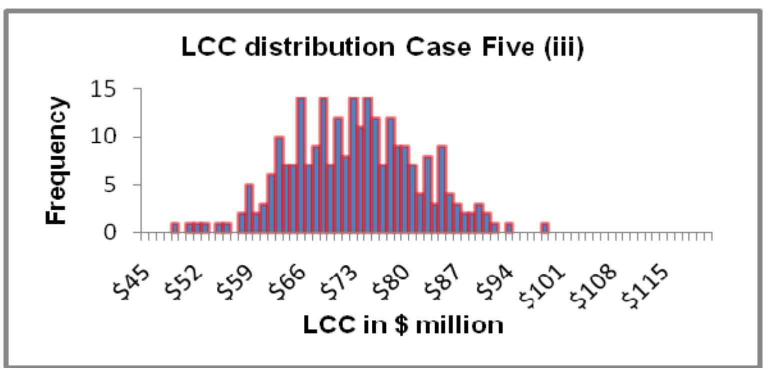
Case Three(i) (in $ million)	
Mean	85.83
Standard Error	0.63
Median	85.79
Standard Deviation	10.14
Range	54.41
Minimum	58.51
Maximum	112.92
Scenarios Count	257



Case Five(i) (in $ million)	
Mean	81.47
Standard Error	0.60
Median	81.57
Standard Deviation	9.62
Range	51.79
Minimum	55.48
Maximum	107.27
Scenarios Count	257



Case Five(ii) (in $ million)	
Mean	79.41
Standard Error	0.59
Median	79.46
Standard Deviation	9.40
Range	51.70
Minimum	53.95
Maximum	105.66
Scenarios Count	257



Case Five(iii) (in $ million)	
Mean	72.64
Standard Error	0.53
Median	72.69
Standard Deviation	8.56
Range	50.36
Minimum	48.51
Maximum	98.87
Scenarios Count	257

Figure 34. LCC Distribution and Descriptive Statistics for Case Five Sub-cases

H. ASSESSMENT FOR PART TWO (CASES FOUR AND FIVE): PROCURE LOWER FAILURE RATES IN CRITICAL COMPONENTS

The second part of the analysis examines and suggests alternative solutions before or during the system acquisition (PBL contracts) during the research and development (R&D) and investment phases, into the components' failure rates (i.e., during the procurement or in a follow on support contract the acquisition team could negotiate a maximum threshold for the components failure rate, in order to achieve a maximum Ao during the weapon's life cycle).

From the Ao distribution assessment (Figure 35), and the results from Case Four and Case Five, it is proven that the most significant factor in Ao improvement remains the improvement in TAT. By improving (reducing) only the failure rate (of one or of all the five components), only a slightly improvement in Ao and readiness risk is achieved, as they still remain below the threshold and target mean Ao the authors set for this report. The same results are produced when only the number of spares is increased in the spare inventory. A combination of a reduced TAT with a reduction in the failure rates and increase in the number of spares in the spare inventory (not for all, but only for the one or two critical components that are the most influential for the Ao) gives significantly better results for the mean Ao (Case Five).

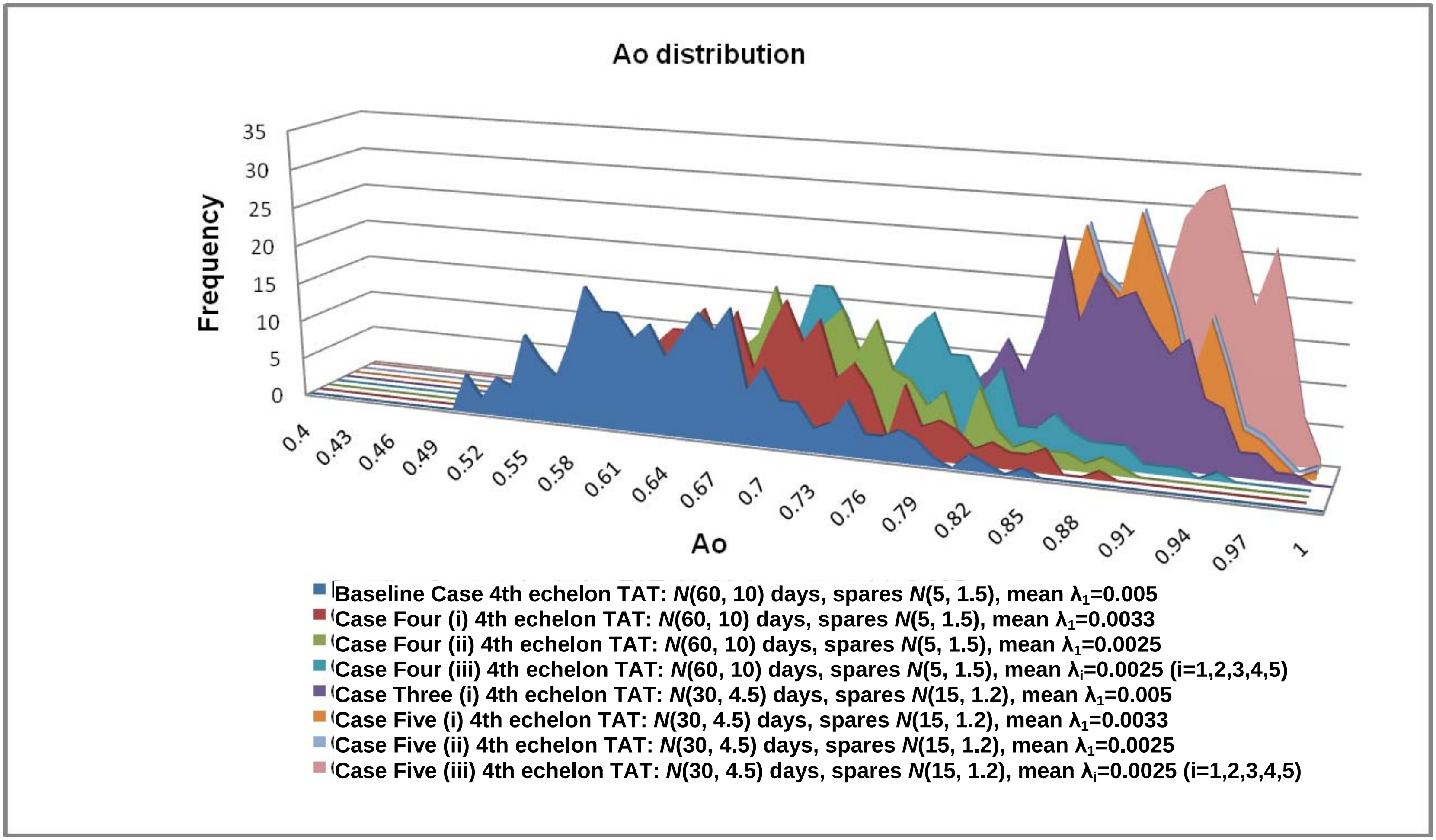


Figure 35. Ao Distribution Chart – Comparison for Part Two

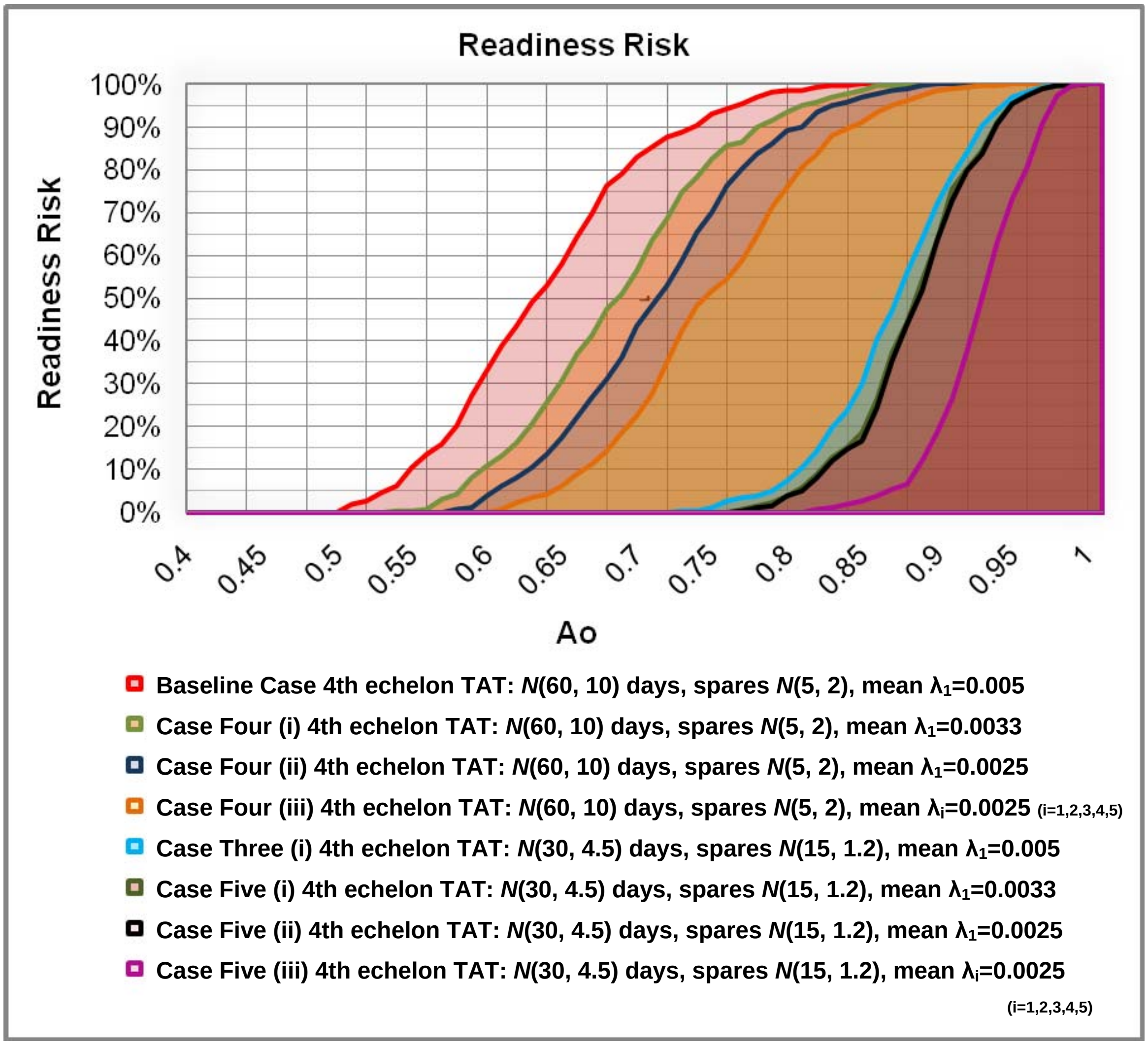


Figure 36. Readiness Risk Chart – Cases Comparison for Part Two

From the readiness risk assessment (Figure 36), it is obvious again that the most influential factor in Ao improvement is TAT. By improving only the failure rate, or increasing the number of spares in the spare inventory, the authors succeeded only in obtaining a slight reduction in readiness risk. Again, a combination of a reduced TAT with a reduced failure rate and increased number of spares in the spare inventory offers a significant reduction in readiness risk (Case Five sub-cases).

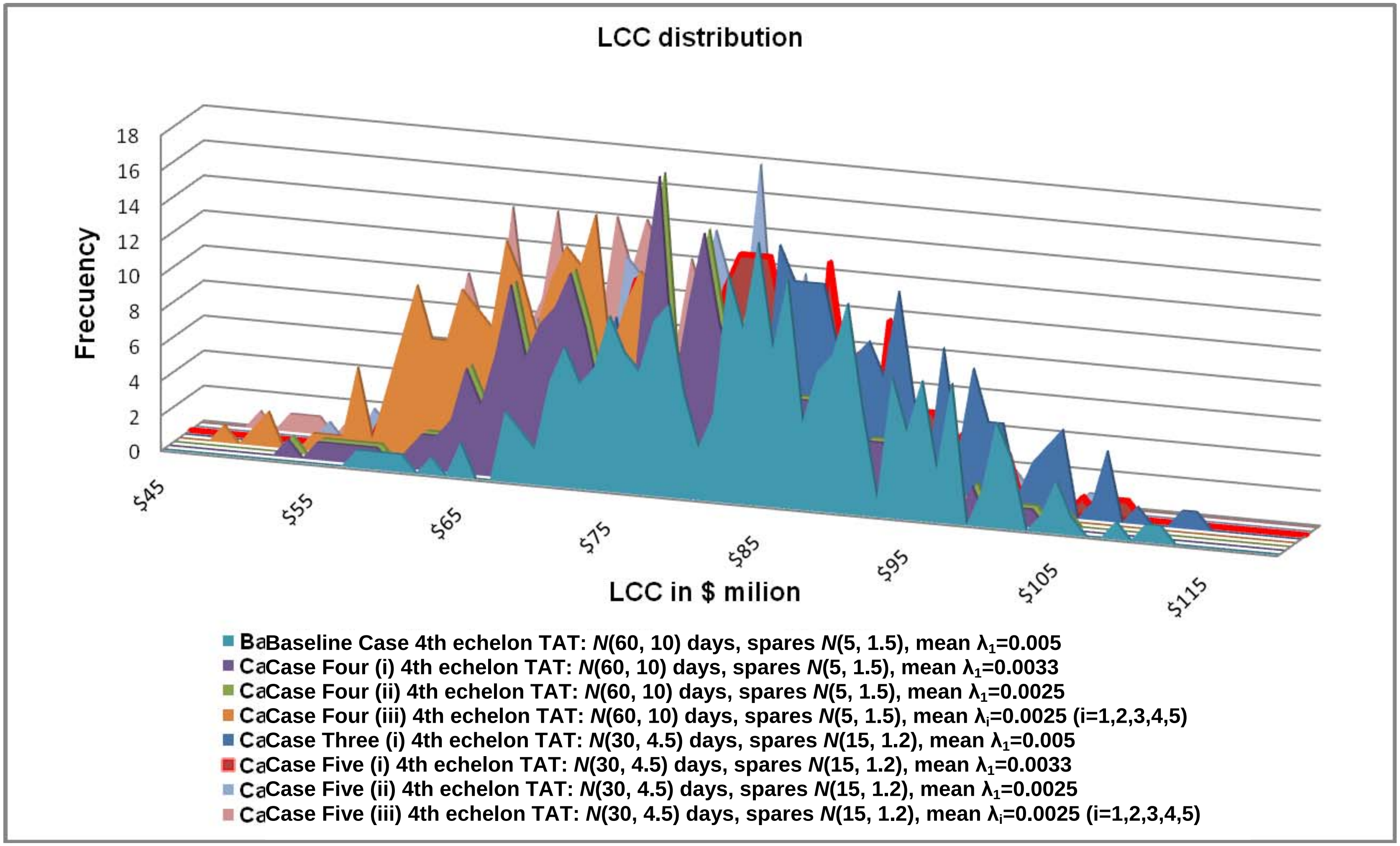


Figure 37. LCC Distribution Chart – Cases Comparison for Part Two

The reduction in the components' failure rates results in an incremental reduction of the LCC, with a total reduction of more than 15% in O&S compared to the Baseline Case in Figures 29, 34 and 37. The savings from LCC in terms of dollars would help determine the breakeven point for procuring reduced failure rates (it is worthy sacrificing an amount, which is less than the savings incurred by reduced LCC, for the procurement of components with decreased failure rates). The acquisition team could negotiate a maximum threshold for the components' failure rates, taking into account the saving in O&S cost. At the he same time, they could achieve an improved weapon's Ao for its life cycle, in conjunction with the other Ao components (e.g., TAT, number of spares in the spare inventory). In the LAV-25 case study, the acquisition team could use $13 million for the acquisition (PBL contact) of reduced failure rates ($\lambda_i \leq 0.0025$) for the five components.

VI. CONCLUSION AND RECOMMENDATIONS

A. MOTIVATION

The ability of the United States Marine Corps to fight and meet the demands of the national military strategy depends on the operational availability (Ao) of its weapon systems and readiness risk (probability of achieving a threshold Ao). Moreover, Ao has been integrated in the acquisition process (Department of Defense, 2009), affecting decision making. The intention of the DoD and the commercial defense industry is to improve weapons system Ao and readiness risk, while at the same time, reducing the total life cycle cost.

This report utilized, as a test platform, the Light Armored Vehicle equipped with a 25mm Gun System (LAV-25), currently employed by the USMC. The modeling scenarios included 76 LAV-25s normally deployed with a Marine Expeditionary Force (MEF) for a life cycle of 20 years, and examined possible alternatives to determine how Ao, readiness risk, and total LCC are affected. This process allowed the authors to identify the total LCC needed for the USMC to maintain specific Ao and readiness risk.

This report provided warfighters and logistics teams the ability to determine which of the Ao's synthetic parameters are more sensitive in terms of maintaining specific levels of mean Ao and readiness risk. These insights will allow them to make sound policy recommendations that will positively influence maintainability, supportability and finally Ao, readiness risk, and total LCC. In addition, the adopted models and the developed methodology of this report provide program managers and contracting officers the ability to ascertain if a maintenance and logistics support proposal being put forth by a potential contractor is truly in the best interest of the government. It will also ensure that a cost effective and reliable weapon system is available for the warfighter.

Another significant aspect of this report is that the adopted models and the developed methodology are not limited to a specific weapon system. By making

minor changes to the model (system components, etc.), and assuming data can be retrieved, they may be applied to many weapon systems currently in use throughout the DoD, such as the Mine Resistant Ambush Protected (MRAP) Vehicle, and aircraft such as the F-22 or F-35.

B. OVERVIEW

The plethora of LAV-25 components, namely over 1,500, would make research on all cross-possible scenarios in conjunction with the input factors impractical and timeless. A good solution was to limit the research to a limited number of parts, especially those that are the most costly to procure or repair, and are considered “critical” (if a failure occurs, the LAV is non-operational). This report concentrated on five major critical components, which represents sixty five percent of the total cost of replacement parts currently maintained by the USMC for the LAV-25.

The simulation modeling was a combination of Arena and Excel spreadsheet software simulations. These two models have been presented and developed by Kang et al. (2009). Even though the Excel spreadsheet model by itself is a simple and useful model for the decision makers (e.g., program managers, logistics designers or financial administrators), it is a “static” model, which does not take into account the dynamic interference between the Ao’s synthetic parameters. For example, a decrease in MTBF will decrease Ao and increase total LCC, because low Ao increases the frequency of repairs and induces higher maintenance costs. Ao is further reduced when these increased maintenance costs eventually lead to budget reductions and force a reduction in the frequency of preventive maintenance. This "vicious cycle" continually lowers Ao, ultimately leading to high-cost corrective (unscheduled) maintenance, which further reduces Ao.

This report estimated distributions of the average Ao, cumulative Ao, and average LCC for 257 scenarios. Each scenario used predetermined mean factor values in accordance with the initial data and assumptions. Correlating the input

data with output results, the authors found which of the input factors had the greatest impact on Ao, readiness risk, and total LCC. The authors then examined alternatives (changed the mean value of the factors that had the greatest impact) and analyzed the results. In accordance with the results and sensitivity analysis, the authors suggested alternative maintenance policies that will achieve the desired impact on maintainability, supportability, Ao, and readiness risk.

The input factors for all scenarios were failure rates of the five components that are critical, the number of spares in the spare inventory, the echelon maintenance turnaround time (TAT), and the Op-Tempo. The outputs were the operational availability (Ao), the readiness risk, and the LCC. As a reminder, the assumption made by the authors for this project, as described in Chapter III, was that LCC was the operation and support cost, including spare, repair, transportation and operations costs.

First, the Baseline Case of this report was developed. This base case model was used to compare the outcomes of all other cases this report developed and investigated. The input data were the failure rates (λ_i) of the components and values with normal distribution for the rest of the input factors (number of spares in the spare inventory, TAT, and Op-Tempo). The authors developed a correlation table, as shown in Table 8, to show the relationship between the input and outputs of the simulation model. The correlation table shows that the factors that most affected Ao were, in order of precedence, the 4th echelon TAT, Op-Tempo, number of spares for component 1 (sensor unit, laser) in the spare pool, and the number of spares for component 5 (engine, diesel) in the spare pool. All other factors had a minor impact on Ao. The factors that were most influential for LCC, in order of precedence, were the Op-Tempo and failure rate of component 2 (control display unit). The findings of the Baseline Case scenario were the drivers for developing the other cases.

The first part of the analysis was Cases One, Two, and Three. In this part the failure rates were retained. This analysis was applicable for existing acquisition arrangements and contracts. The second part of the analysis was Cases Four and Five. In this part, the failure rates were changed. This analysis was applicable for developing new arrangements and contracts, or modifying the existing ones.

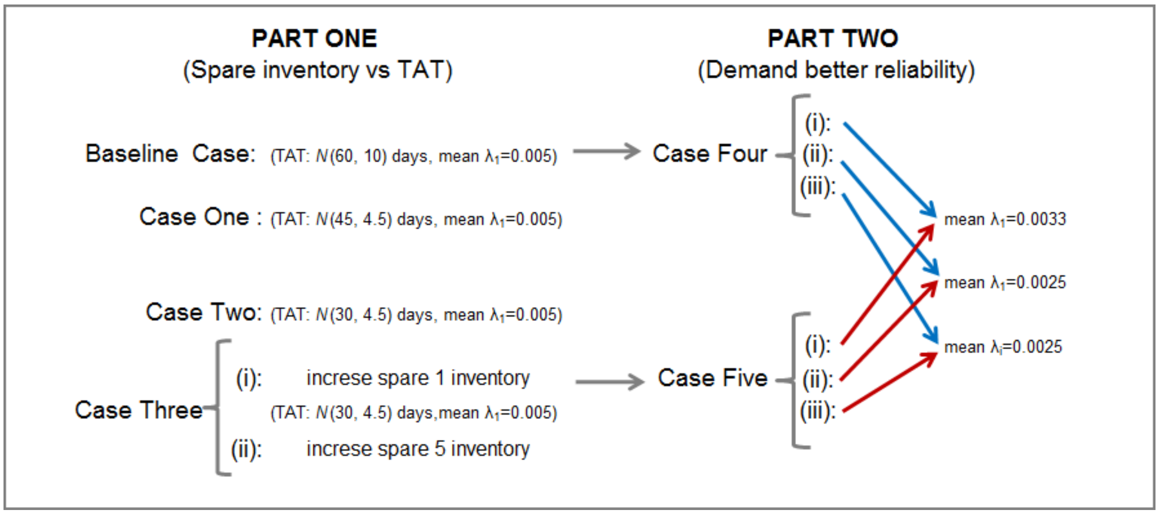


Table 10. Summary of Cases

In Case One, the input factor of 4th echelon TAT was set to be N(45, 4.5) days. The rest of the factors were identical as the Baseline Case. There was improvement for the mean Ao and the readiness risk. However, the mean Ao remained below the target mean Ao of 0.85. The mean LCC did not significantly change.

In Case Two, the input factor of 4th echelon TAT was further improved and set at N(30, 4.5) days. There was further improvement for Ao and readiness risk. However, the mean Ao still remained below the target mean Ao. The mean LCC did not significantly change.

Case Three was divided in two sub-cases. For both sub-cases, the input factor of 4th echelon TAT was set as in Case Two (N(30, 4.5) days). For the one sub-case, the input factor of number of spares in the spare inventory for

component 1 (sensor unit, laser) was increased. For the other sub-case, the input factor of number of spares in the spare inventory for component 5 (engine, diesel) was increased. For sub-case (i), when the spare 1 inventory increased, the mean Ao was improved above the target mean Ao. Furthermore, there was noteworthy improvement in readiness risk. The mean LCC was slightly increased. Therefore, for developing the next case the change in number of spares for component 1 was used.

Case four used the same input data as the baseline case, except the failure rates. Three distinct sub-cases were created. In the sub-cases one and two, the mean failure rate of component 1 (sensor unit, laser) was improved from λ=0.005 to λ=0.0033 and λ=0.0025, respectively. In the third sub-case, the failure rates of all five components were changed to λ=0.0025. For all sub-cases there was improvement for mean Ao and readiness risk, but below the threshold and the target mean Ao. The LCC was incrementally reduced from sub-case one to sub-case three.

Case Five was a combination of Cases Three and Four. The input factor of 4th echelon TAT was set as in Case Three (*N*(30, 4.5) days). Then, three sub-cases were created. Each sub-case used the failure rates of the respective sub-cases as in Case Four. The mean Ao and readiness risk were significantly improved, well above the threshold and target mean Ao. The LCC was incrementally reduced.

C. CONCLUSION

1. The turnaround time (TAT) has the biggest impact on Ao and readiness risk.

The decision makers and the warfighters should focus on how to improve this factor.

2. Keeping only a large spare inventory, without improvement in TAT, does not have a significant impact on Ao and readiness risk improvement. Furthermore, it only increases the LCC.

The research demonstrated that by increasing only the number of spares in the spare inventory there is almost no change in readiness risk. A combination of a reduced TAT with an increased number of spares in the spare inventory gives further improved results for the readiness risk.

3. A combination of TAT improvement and reduced failure rates in critical components has a significant positive impact; namely, significant Ao and readiness risk improvement, and at the same time, LCC reduction.

The report indicates that if there is improvement in the Ao, simultaneously there is a contribution into the reduction of LCC.

4. PBL seems to be a sound approach. The origin of problems in PBL arrangements are not intrinsic but from inappropriate implementation.

The simulation model that this report adopted and the methodology that was developed can be utilized as a guide to negotiate better performance for acquisition. It can assist trade-off decisions between performance and TOC. The savings from LCC in terms of dollars would help determine the breakeven point for procuring components with decreased failure rates. The acquisition team could negotiate a maximum threshold for the components' failure rates, taking into account the saving in O&S cost. Cases Four and Five indicate the methodology that the acquisition officials and decision maker may follow. Many other setups (cases) can be created and examined in order to come to a sound decision.

5. Consideration should be given to PBL implementation. There are strong indicators that PBL is better when implemented in subsystems or component levels.

The sources that this report reviewed indicated that both the DoD and private industry incurred better results when implementing PBL in a subsystem or component level. Modeling and simulation can assist the decision maker and the warfighter to make assessments on the entire system. Appropriate metrics are of significant importance for developing simulation models and evaluating outcomes.

D. IMPLICATIONS

Turnaround time is the most significant factor affecting operational availability, readiness risk, and life cycle cost. Funding only for spare inventory is not the optimal allocation of tax dollars; reducing TAT by improving maintainability and supportability (the two components of TAT) will result in the need for retaining a smaller spare inventory. Furthermore, trying to enhance only the MTBF of a system or subsystem will not by itself produce the desired outcome for increased Ao and reduced total LCC. A combination with TAT improvement would multiply the outcome benefits in terms of increased Ao, reduced readiness risk, and reduced total LCC.

1. Under Secretary of Defense for Acquisition, Technology & Logistics

Pursuing improvement in TAT should be a key focus in the policy and directions regarding all systems, regardless of their point in the acquisition life cycle. The appropriate mix of TAT and MTBF is the task of acquisition managers and decision makers.

PBL is indeed directed for implementation. However, it is not directed to be implemented in the subsystem or component level, as this research indicated would result in optimum outcomes. Furthermore, tools such as modeling and simulation, and appropriate measures tied to the desired outcomes, are not widely used.

The above should be investigated and incorporated in the DoD's policies. USD (AT&L) is the overarching authority. USD (AT&L) and the respective agencies have the responsibility for overseeing the implementation of policies and directions they have issued. USD (AT&L) should ensure the proper communication between the acquisition and logistics communities. Oversight and communication would diminish the possibility of issuing policies that are not being practiced. The title of the USD (AT&L), by itself, depicts the importance of close collaboration between acquisition, technology, and logistics.

2. Acquisition Managers / Decision Makers (Agencies, Boards, PMs)

Management should take into account the life cycle management and total LCC. Focusing only on the procurement cost will not result in the best return on the invested funds. The sustainment cost (operation and support) is 60%–80% of the total ownership cost (Naegle, 2008). For DoD objectives, many times performance is the primary criterion rather than cost. Managers are called to decide for trade-offs between the available funds and the desired performance.

Outcomes in terms of Ao, readiness risk, and total LCC would be staggeringly improved by investing mainly in TAT. Secondarily, determining the appropriate level of failure rates and spare inventory would further augment outcomes. The model adopted by Kang et al. in this report and the developed methodology provides managers and decision makers a tool that is flexible and applicable throughout all phases of the acquisition life cycle. In addition, such tools can be easily used when the desired outcomes change. Also, they are easily understood, and thus easy to implement for all stakeholders and mainly the warfighters. They are applicable to all systems; in the development phase, relatively new and legacy. The use of such a tool diminishes the required workload.

Performance-based logistics is the DoD's preferred acquisition arrangement. Whether to follow PBL, and what is the proper implementation in order to achieve optimum results, is the responsibility of acquisition managers. They should consider pursuing PBL implementation in a subsystem or component level. Managers, except the accurate requirements that should be requested from the user, should define and decide on measures and metrics related to the desired outcomes. Close teamwork with the user is required in order to monitor changes and refine the acquisition strategy and/or life cycle acquisition management. The use of M&S is connecting all subsystems, and illustrates the effect of decisions in the system as a totality. Business case analysis can be supported with the model adopted as part of this project or a similar tool.

3. Contracting Officers

The use of M&S will help contracting officers have a clear picture as to what extent the desired outcomes can be achieved. This will help contracting officers to create and use the appropriate contracting vehicles, mitigating the risk for the government. The use of M&S during negotiations provides them with solutions to different offered alternatives. Such models can also assist contracting officers in developing the right incentives for contractors to perform beyond the required objectives, especially for PBL arrangements.

Performance-based logistics and the shift from buying spares to buying performance drastically change the way a contracting officer should think and act. The workload for the contracting officers increases, as they have to oversee contractor performance during the life cycle of the system. Contracting officers need to develop a plan and methodology for measuring performance against predefined standards. Proper metrics tied to the desired outcomes and suitable tools, such as the model this project adopted, can reduce workload. Additionally, PBL requires knowledge from contracting officers that is beyond their expertise.

Hence, closer collaboration and coordination with maintenance and logistics specialists is essential for successful contract management of the system.

4. Maintenance and Logistics Managers

The improvement of turnaround time is mainly the responsibility of maintenance and logistics managers. They should provide areas with a potential for improvement and the respective methods that will result in ameliorate outcomes. Particularly, the logistics community develops and uses more M&S tools than every other specialty. The critical role that M&S can play in acquisition management, which this project illustrated, reveals the necessity for closer cooperation between the acquisition, maintenance, and logistic communities. This will increase the workload and responsibilities of all involved maintenance and logistics managers. However, the development of M&S tools with the contribution of all the concerned parties will lead to a more realistic approach of the model and simulation results of better quality. An increase in workload also stems from the continuous monitoring of requirements and processes that is necessary for updating and adjusting tools and methods.

Regarding PBL, maintenance and logistics management is not following traditional approaches. Accordingly, a paradigm shift in maintenance and logistics ways of management is required; manage performance and desired objectives rather than how to achieve them. Maintenance and logistics managers should contribute with their expertise in the development of the appropriate metrics.

5. Warfighter

Modeling and simulation can assist the warfighter to find the Ao and readiness risk for the level of sources currently available. The model this project adopted and the developed methodology will help USMC to determine the Ao and readiness risk that is achievable with the available spare pool, the existing failure rates, maintenance times, and logistics delay times. The degree of accuracy of inputs used in M&S tools determines the quality of the results.

Therefore, warfighters need to determine and provide with certainty their operational requirements (mean Ao and readiness risk) and update them as necessary. Close and uninterrupted cooperation with acquisition and logistics personnel is required to develop and adjust the appropriate M&S tools and performance metrics. This is a requisite especially for PBL. M&S can also help the warfighter to understand the scarcity and limitations of resources (funds, spares, personnel, maintenance times, logistics capabilities, etc.) and the impact on operational availability, consequently in operations, of proficient management.

6. Taxpayers

The methodology and tools indicated in this report may assist in the avoidance of cost overruns paid by the taxpayers for the public goods of national security and national defense, because of poor performance and ambiguous metrics. Proper use and implementation of acquisition tools and methods would result in improved performance and decreased total LCC.

E. RECOMMENDATIONS

1. The DoD should further research the impact that TAT has on Ao, readiness risk, and total LCC. The Dod should investigate alternatives for improving TAT.

2. The DoD should develop case studies for other major weapon systems and compare findings. Use of more realistic data that this project was able to collect is recommended.

3. The DoD should consider PBL implementation in a subsystem or component level and mandate the use of Ao and readiness risk as performance measures. They should also provide initiatives for developing any other metric appropriate for each individual case and tied to the desired outcomes.

4. The USD (AT&L) should issue directives for focus on TAT and mandate the use of M&S tools for use in life cycle management. Finally, they

should enhance collaboration and coordination between acquisition and logistics communities, as well as investigate the potential of an integrated team managing the system throughout its entire life cycle.

5. The USD (AT&L) should examine what paradigm shift in the organizational behavior of agencies is needed in order to implement PBL, how it can be accomplished, and provide appropriate training. Training should be common for all different specialists: acquisition, maintenance, logistics, and warfighters.

6. Acquisition, maintenance, and logistics managers should cooperate more closely in the development of M&S and the appropriate metrics. They should also collaborate and coordinate in developing and implementing PBL arrangements.

7. Warfighters should use M&S tools for setting goals that are achievable with the available resources. Alternatively, they should use M&S tools to set the resources requirements for achieving desired objectives. They should provide acquisition, maintenance, and logistics managers with accurate and updated demands and objectives.

8. The USMC should use the model adopted and the developed methodology in this project in order to improve Ao and readiness risk. They should investigate methods to improve TAT in the fourth echelon of maintenance. Lastly, they should consider PBL contracts for the support of LAVs with the five critical components selected for this project’s case study.

APPENDIX: LAV-25 SYSTEM DESCRIPTION

A. PROGRAM HISTORY

The concept of the light armored vehicle (LAV) was first vetted by the United States military services in the late 1970s. At the time, military strategists were devising ways in which to employ highly mobile and rapidly deployable forces vice large entrenched units primarily to deal with the emerging threat posed by the Middle East. Initially, the United States Army led the way in LAV concept development and research, but eventually determined that deploying forces utilizing LAVs was not in its best interests. At the same time, the United States Marine Corps, always tasked with deploying its forces rapidly, was searching for a means by which to enhance the mobility, lethality, and firepower of its units. They saw possible benefits of the LAV and under the leadership of Commandant Al Gray, obtained specially allocated funds from Congress and began the preparations for procurement and testing of LAVs being built by GM Defense Systems in Canada and fielded by the Canadian Armed Forces.

In the early 1980s, testing of numerous LAV-Grizzlies on loan from the Canadian military began at the Marine Corps Air Ground Combat Center, 29 Palms, California. The testing proved successful and the Marine Corps determined that that the LAV met all the requirements it needed, and in September of 1982, a production contract was approved with GM Defense Systems, Canada for the production of the LAV in six different models: anti-tank, mortar, 25mm, logistics, maintenance and recovery, and command and control.

The first LAVs were deployed in July 1985 to the 2nd LAV Battalion, Camp Lejuene, NC, followed closely by deployments to the 1st LAV Battalion, Camp Pendleton, CA and the 3rd LAV Battalion, 29 Palms, CA. Since its inception, the LAV, in all of its configurations, has proved its worth, being used extensively in

wartime, natural disasters, and civil peacekeeping missions including Panama, Kuwait, Iraqi, Afghanistan, and following the terrorist attacks of September 11, 2001.

As the LAV continues to prove its worth, the Marine Corps plans to extend its useful life beyond the year 2015, and the United States Army, in a reversal of initial findings, is now fielding the LAV in highly mobile units known as Stryker Brigade Combat Teams.

B. CONFIGURATION DESCRIPTIONS

The basic LAV fielded by the Marine Corps is the LAV-25, an 8x8 wheeled, lightly armored combat vehicle. Expanding on this basic model, the Marine Corps has created its Family of Light Armored Vehicles (FOLAV) consisting of LAVs available in the following six different configurations:

- LAV-AT (Anti-tank-TOW missile system)
- LAV-C2 (Command and Control)
- LAV-R (Recovery)
- LAV-LOG (Logistics)
- LAV-M (Mortar)
- LAV-MEWSS (Mobile Electronic Warfare Support System)

The workhorse of the Marine Corps LAV fleet, and the focus of this research project, is the LAV-25, as seen in Figure 38.

Figure 38. LAV-25 (From: Olive-Drab, n.d.)

The LAV-25 consists of a M242-25mm chain gun; it is designed to operate in all terrains and in all weather conditions, and includes night vision capabilities. When necessary, the LAV-25 can be configured to operate amphibiously within 3 minutes. The LAV-25 can be transported by air utilizing a CH-53 E, C-141, C-130, or C-5, and cost approximately $900,000.

Multiple sources on the Internet are available for information on LAVs, such as the following:

- http://www2.marines.mil/unit/hqmc/Pages/default.aspx (The Head Quarters Marine Corps Web site)
- http://www.globalsecurity.org/military/systems/ground/index.html
- http://www.olive-drab.com/idphoto/id_photos_lav.php3.

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